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FINAL TEST REPORT

SHIELDED SOUNDPROOF BOOTHS

78-03645A

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CONTRACT SCC-28160

United States Department of State
and
Western Electric Company, Incorporated

PERIOD COVERED: OCTOBER 24, 1960 TO MARCH 31, 1961
DATE OF THIS REPORT: APRIL 27, 1961

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Prepared by Bell Telephone Laboratories, Incorporated
On behalf of Western Electric Company, Incorporated
120 Broadway, New York 5, N. Y.

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PREFACE

This technical report is submitted in accordance with the provisions of Contract SCC-28160 between the United States Government and the Western Electric Company. The contract provides for the accomplishment of research and development necessary to the testing and evaluation of two shielded soundproof booths. The booths are intended to provide an operationally secure environment for the conduct of conferences and machine operations of a sensitive nature. The contract solicits recommendations, based upon the technical evaluations, for the improvement of the structures.

Presented in the report, therefore, are the techniques and results for acoustic, magnetic, and electromagnetic measurements performed on the booths. Also offered are the contractor's interpretations of how technical performance relates to the security problem, as well as certain recommendations for the design and operation of such booths.

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Section I. PURPOSE OF THE STUDY AND SUMMARY OF PRINCIPAL RECOMMENDATIONS AND CONCLUSIONS

1. PURPOSE

The purpose of this study is to examine the problem of providing a secure environment for two different types of operations: the first, conversations of a highly sensitive nature; the second, protection of cryptographic machines and similar electromechanical devices. In the second case, spurious radiations of intelligence value may have acoustic, electromagnetic, or magnetic forms. In the first case, although the initial radiations of intelligence are speech sound waves, eavesdropping microphones with electromagnetic or magnetic transmitters can be brought into, and concealed within, an acoustic isolation structure. Security procedures and inspection methods can aid in preventing access by clandestine radio and magnetic transmitters, but such methods cannot be totally effective.

From the technical standpoint, therefore, the protective measures for both types of operations are basically similar and pose nearly identical shielding requirements. Following these assumptions, the present study considers totally enclosing structures to isolate speech, radio transmissions, or other information-carrying signals originating inside from points where they can be detected usefully. General recommendations are based upon study of methods for isolating not only sound, but electromagnetic and magnetic fields as well. In addition, these recommendations consider methods for circumventing such isolation by clandestine devices. Specific recommendations are drawn from measurements and technical evaluations of two isolation booths designed to provide an operationally secure environment for men or machines confined within the booth.

In general, it is clear that structural isolation of signals can never be absolute. We consider that realistic technical objectives for such structures are:

1. To attenuate signal fields sufficiently to reduce them below usable levels, considering both the noise level at accessible points and the opponent's ability to separate signals from noise.
2. To resist penetration by listening devices and, if penetrated, give clear and obvious evidence of the fact.

To these technical objectives must be added the aesthetic one: that the structure be acceptable for transient occupancy by humans. Also, it is imperative that operational objectives for testing isolation effectiveness of particular installations be formulated. Implicit in all the objectives are the obvious ones of size and weight limitation, portability, complexity of construction, and cost.

Both booths evaluated in this study are intended to be erected within a parent room at least four feet greater than the booths in every over-all dimension. One of the booths is a double-wall structure constructed of clear plexiglass braced with duraluminum members. Though this booth was not shielded electromagnetically, a commercially available screen room was placed inside as a temporary test arrangement. This booth was designed and constructed by the Airtronics Company. The other is a three-wall metal structure, with an inner shell which is mechanically isolated from the middle supporting shell. The preliminary design for this booth was carried out by Armour Research Foundation and it was constructed by Ace Engineering Company.

The technical evaluations involved measurements of acoustic attenuation at audible and ultrasonic frequencies, attenuation of electromagnetic radiation over the frequency range 12 to 10,000 mc, and attenuation of audio-frequency magnetic fields. These measurements were made at a number of locations in an effort to detect any weak spots or "holes" in the structure. In addition, a number of tests were carried out to determine means for masking the residual external signals which otherwise might be detectable.

The technical results of these tests and their interpretations suggest certain methods for achieving the most secure environment with an enclosing structure. Strongly implied in such recommendations, but mainly of subordinate rank, is the aesthetic consideration previously mentioned.

2. SUMMARY OF PRINCIPAL RECOMMENDATIONS AND CONCLUSIONS

In order to meet the first objective given in paragraph 1, namely, to attenuate signal fields sufficiently to reduce them below usable levels, the following measures are necessary:

1. For acoustic and magnetic fields, a combination of structural attenuation and external masking noise such that maximum realistic signals inside produce external residual signals whose spectrum levels are equal to, or less than, the spectrum level of the noise at all frequencies of importance.

2. For electromagnetic fields, structural attenuation greater than 60 db at all frequencies between 100 kc and 1 kmc, and 30 db between 1 and 10 kmc, measured with a "worst case" criterion as explained in Section III, paragraph 4.

In order to meet the second objective, i.e., to resist penetration of the structure, the following measures are necessary:

1. The structure should be designed so that once assembled, it must be destroyed to be breeched.
2. Both inside and outside surfaces of the structure should be sealed by selectively reflecting paint or brittle plastic which can be matched only after detailed chemical, reflectivity, or optical analysis. No unsealed surfaces should remain in the structure.
3. The use of transparent material in the construction of the acoustic shield might provide additional security <u>if it is used in combination with the previous measures</u>, and if it does not contain opaque members or highly refracting-reflecting seams and joints within its walls. If such a clear acoustic shield is used, a separate sealed electromagnetic shield is a necessary measure against electromagnetic transmission.

Results of the tests on the two booths examined in detail reveal that neither in its present form is totally adequate nor represents all that current technology can provide; both require additional design and development work. The two booths represent valid but somewhat divergent approaches to the problem. The plexiglass booth obviously weighs acceptability and aesthetic factors more heavily than does the metal booth; design of the latter favors technical security.

At this point, both booths should be considered to be experimental stages in a continuing program of design and development of such structures. In this light, the following conclusions and recommendations are stated.

The plexiglass booth contains the following inadequacies:

1. Opaque members within its walls
2. Opaque seams and joints
3. Lack of surface sealing
4. Demountable construction.

In addition, its relatively low acoustic attenuation is such that under some conditions of installation, masking noise greater than that considered desirable for comfortable occupancy would be necessary. The screen room supplied for the test installation and placed inside the acoustic structure contains opaque members. This arrangement not only vitiates the notion of an easily inspectable structure but also invites concealed radio devices outside the screen and inside the acoustic structure. Clearly, new design and development work to overcome these shortcomings is called for before such a room is considered seriously for anything but interim or "stop-gap" use.

The metal booth, while also unsuitable for operational use in its present form, represents a more sound engineering beginning toward a satisfactory enclosure. Fairly straightforward additions and modifications could satisfy all of the previously stated requirements, with the possible exception of aesthetic factors and size and weight limitations.

3. COMMENT

Security is, of course, relative, and criteria of security must be tailored to suit particular situations. These criteria must involve a judicious merging of both technical (objective) and aesthetic (subjective) considerations. There is obviously little point in having a technically secure structure if it is so unsightly, uncomfortable, and unpleasant that no one will use it. Equally ridiculous is the comfortable, pleasant booth in which everyone happily gathers to confer around a multitude of clandestine transducers.

This study has centered primarily on the technical requirements for a secure structure. On the other hand, we have not been blind to subjective factors affecting use of the structure. Knowing the stakes involved in the security situation, our recommendations consciously stress technical security because we feel it is the primary requisite. Livability and aesthetics should be subordinated to it, and should be recognized as subordinate by potential users. Such an attitude must be cultivated by instruction and indoctrination. In the long run, this would seem a cheap price to pay for additional security.

Similarly, the present-day technology of clandestine listening devices, passive and active, calls for both acoustic and electromagnetic shielding. Too, the technology of miniaturized radio devices is advancing rapidly. Another jump downward in size is certainly not far in the future. Detection of such devices is already a formidable task. Soon it will become even more problematical. Thus, it is not only today's capabilities for concealed monitors, but the advances in prospect, which lead to the necessity for electromagnetic as well as acoustic shielding.

Indeed, an adequate structure for today is not likely to remain adequate for long. Development of protective enclosures must not be a "one-shot" affair if effective protection is to be maintained. New methods for transmission through shields, involving γ rays or X rays for instance, may well be developed. Such possibilities when they become realities will call for new countermeasures.

To keep abreast of technical capabilities, a continuing effort in the design and development of security structures is strongly implied. Both booths tested represent steps in the right direction and constitute differing partial solutions to the problem. While neither is unqualifiedly adequate for field application, both are highly useful for experiment and study. Facts learned from tests on these prototypes can form important bases for specification and improvement of future structures.

Operational use of isolation booths involves a myriad of problems in addition to the subjective one mentioned above. Many among these are operational security practices on which we do not feel qualified to comment. It is clear, however, that only to the detriment of over-all security can technical security and operational security procedures substitute for one another. Rather, they must be made to supplement one another.

Operational tests of isolation effectiveness in particular installations are primarily technical in nature, and we feel such performance tests are crucial to any realistic application of isolation structures. In particular, a rigorous series of tests should be carried out routinely after every installation to assure its adequacy.

The minimum acceptable performance must be stated explicitly as a set of requirements. A truncated version of these tests should be part of the maintenance and inspection routine. Since methods and equipment for carrying out these tests are closely related to the final structural configuration as well as to other operational considerations, they are best formulated after further development of the structure itself. However, it is clear that to neglect these technical-operational routines, or to leave them ill-defined, could negate the entire concept of a secure environment.

In sum, the problem of providing a secure environment involves a complex of technical and operational factors with all the aspects of measure-countermeasure warfare. To approach the problem from any but a unified standpoint incorporating all these considerations could well lead to a "perilous" environment — the opposite of the intended effect. Indeed, nothing short of the most advanced technical measures, coupled with operational routines based on careful analysis of the risks and values, is sufficient.

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Section II. SUMMARY OF TEST RESULTS AND GENERAL RECOMMENDATIONS

1. REPRESENTATIVE TEST RESULTS

The technical performance of the two rooms can be roughly indicated and a comparison can be drawn by quoting average "midband" figures obtained in the various tests. These figures are essentially taken out of context and do not reflect the detailed performance of either room. Performance is spelled out with some care in the following sections, and these sections must be consulted for broad-range comparisons. The midrange figures do, however, provide a simple metric that is suggestive of the over-all results. Typical acoustic, electromagnetic, and magnetic attenuations measured in the tests are shown in Table I.

Table I

NOMINAL ACOUSTIC, ELECTROMAGNETIC, AND MAGNETIC ATTENUATIONS

	Nominal Attenuation (db)*		
Booth	Acoustic (midaudio, 1 kc)	Electromagnetic (1000 mc)	Magnetic (midaudio, 1 kc)
Plexiglass	30	60	5
Metal	50	75	30

*Measured under conditions prescribed in following sections, rounded to closest 5 db.

Articulation tests were also carried out to determine the intelligibility of speech signals available externally from a speaker inside the booth, and the external noise levels necessary to mask air and contact pickups of the speech sounds transmitted through the booth walls. The results of these tests can be summarized in a manner similar to the foregoing measurements. Intelligibility scores for air and contact listening in the external ambient noise of the parent room are given in Table II. The nominal over-all levels of external masking noise, and the approximate, asymptotic distribution of spectral energy for the most effective masking, are shown in Table III for contact pickup, and in Table IV for air pickup.[1] The

[1] The rms reference sound pressure for all decibel values given in this report is 0.0002 dyne/cm^2.

results are shown for two intensities of the inside speech. The first corresponds to a raised voice at a distance of 1 meter in free space and is a full conversational level. The second is about as loud as a man can talk without shouting.

Table II

AVERAGE INTELLIGIBILITY SCORES FOR MONOSYLLABIC WORDS — AMBIENT MASKING — LOUD (78-DB) TALKER

Booth	Air Listening (per cent)	Contact Pickup (per cent)
Plexiglass*	38	94
Metal†	28	52

*State Department installation: over-all ambient = 64 db.

†Bell Laboratories installation: over-all ambient = 46 db.

Table III

MASKING LEVELS FOR CONTACT PICKUP

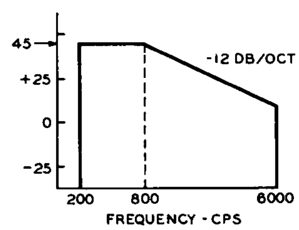
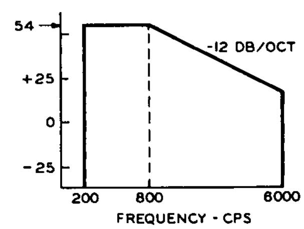
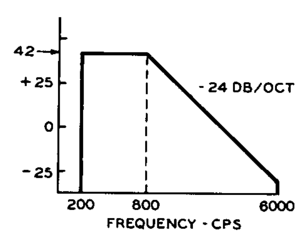
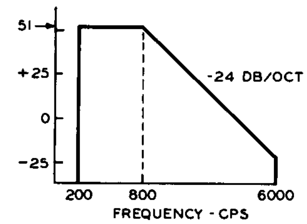
	Inside Speech Level 69 db (re 0.0002 dyne/cm^2) Over All		Inside Speech Level 78 db (re 0.0002 dyne/cm^2) Over All	
Booth	Over-all Masking Level (db)	Asymptotic Optimum Shape	Over-all Masking Level (db)	Asymptotic Optimum Shape
Plexiglass	76		85	
Metal	71		80	

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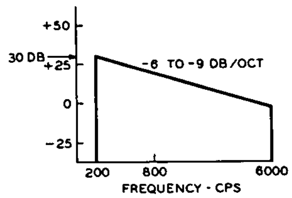
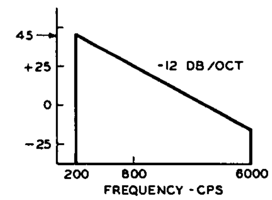
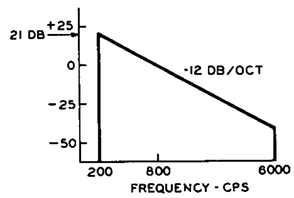
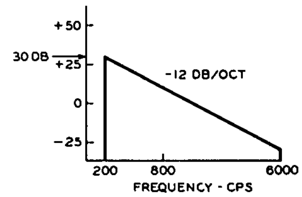
Table IV

MASKING LEVELS FOR AIR PICKUP

	69-db Talker		78-db Talker	
Booth	Over-all Masking Level (db)	Asymptotic Optimum Shape (db)	Over-all Masking Level (db)	Asymptotic Optimum Shape (db)
Plexiglass	60*		68†	
Metal	44		53	

*Using attenuation measured at Bell Laboratories installation.
†Using attenuation measured at the State Department installation.

The over-all masking levels given in Tables III and IV are for noise spectra shaped approximately as shown in the diagrams. To achieve the equivalent masking with noise having a uniform (flat) spectrum would require over-all levels appreciably higher.

In addition to masking air and contact pickups by external acoustic noise, qualitative experiments were made on the metal booth to mask these pickups by mechanical vibration of the outer wall. When a vibrator[2] was placed in contact with the wall on which the pickup was being made, it easily and amply masked the

[2]In these cursory tests, the vibrator used was the Bell 5-A Artificial Larynx, held in contact with the outer wall.

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contact pickup for the loud (78-db) talker. In addition, it radiated noise into the air at an over-all level of 54 db and with a spectral shape that effectively masked the airborne signal in the vicinity of the wall. The noise transmitted into the booth was essentially at or below the normal ambient level. These tests were not carried out on the plexiglass booth.[3]

2. CONCLUSIONS AND RECOMMENDATIONS

From all the technical standpoints considered in the tests, the metal booth is clearly superior to the plexiglass booth. Both, however, require certain technical improvements. The subjective question of acceptability and livability is somewhat debatable. Assuming a pleasant, large parent room, the plexiglass booth, without the r-f shield, undoubtedly would be more desirable. Because of the importance attached to the use of such booths, possible aesthetic objections should be subordinated to technical security, and should be assumed to be surmountable, at least in part, by appropriate instruction and indoctrination. It would seem that the stakes warrant doing everything of a technical nature that can be done practically to insure a secure structure. Within this frame of reference, therefore, the following general recommendations can be stated.

a. General Recommendations

Use should be made of suitable materials and structural features, giving careful regard to limitations of weight and required construction skills, to obtain maximum acoustic isolation. No new research is required, only careful attention to engineering design.

Electromagnetic shielding should be similarly maximized. Again, careful engineering is the key.

The structure should be designed so that once assembled it must be destroyed in order to breech it. Such structural techniques are available and can be adapted to the necessary materials.

Inspection for enclosure integrity should depend upon observation of inside and outside surfaces. An inspectable seal might be achieved by a coating, perhaps a selectively-reflecting paint, sprayed on after assembly. Paints are available, but other suitable coatings, such as brittle plastics, might be developed.

Ease of inspection does not necessarily depend upon transparency of a structure. It seems more sound to inspect inside and outside surfaces than to depend

[3]It has since been learned from representatives of the State Department that mechanical vibration of the outer wall of the plexiglass booth is not particularly satisfactory because of the noise transmitted into the booth.

upon transmitted light with all the attendant problems of reflection and refraction at joints and seams. In addition, it is a fundamental law of nature that a conducting electromagnetic shield cannot be transparent to visible radiation. Therefore, important parts of any security structure will not be transparent and must be protected in other ways.

The air-conditioning ducts and power lines are vulnerable points in any enclosure. Careful engineering of filters and traps to prevent leakage or penetrations via these accesses is requisite. However, in extreme cases, it may be feasible to make the enclosure entirely self-supporting for periods of hours, as is a submarine. Enclosed air purifiers and coolers, and storage batteries for lighting would eliminate the need for ducts and ports. Thereby, the outer and inner surfaces could be completely sealed.

Noise masking, both acoustic and magnetic, should be used to reduce the useful signal output from the structure. In the acoustic case, this can often be accomplished effectively by vibrating the outer wall directly, using electromechanical drivers. This method can, in certain cases, give efficient masking for both contact and air pickup, with negligible annoyance inside the enclosure.

An adequate structure for today is not likely to remain adequate for long. Development of protective enclosures must not be a "one-shot" affair if effective protection is to be maintained. For instance, new methods for transmission through shields will be developed. It is also conceivable that radioactive material (γ-ray emitter) could be modulated in spatial position and the doppler shift detected externally. Also, high-energy X rays could penetrate the structure and afford an information carrier. Such possibilities, when they become realities, will call for new countermeasures.

Particular study should be given to techniques for routine checking of the structure. An attempt should be made to develop test methods which are simple and foolproof, and can be carried out by technically unskilled persons if the need arises. The methods should be made to depend as little as possible upon the characteristics of the parent room and the particular installation.

For routine purposes, measurements of the "go, no-go" type could be made adequate. Some study should be devoted to developing test transmitters and receivers that could accomplish the desired tests with a minimum of equipment complexity. For instance, a simple spark-gap device might conceivably be useful as a combined acoustic and electromagnetic transmitter.

Specific conclusions and recommendations can be similarly summarized.

b. Specific Conclusions

Neither booth by itself provides an adequately secure acoustic environment. External masking sources are indicated for both structures to render air and contact pickups impotent. Acoustic masking can be accomplished easily by external audio noise generators and loudspeakers. In the case of the metal booth, mechanical vibrators in direct contact with the outer wall provided easy and sufficient masking of air and contact signals. To mask strong speech (78 db) securely, the requisite external masking levels produced levels inside the booths that were negligible in the case of the metal booth, but were only marginally tolerable for the plexiglass booth. The acoustic attenuation of the plexiglass structure should be improved if it is to have any appreciable security safety margin.

The over-all radio frequency attenuation of both booths is sufficient to reduce most transmissions of milliwatt power to useless levels. The plexiglass booth with its enclosed screen room is, however, an unfortunate arrangement. Not only does this vitiate any notion of an easily inspectable structure, but it also invites concealed radio devices outside the screen and inside the acoustic structure. This feature should be corrected.

Neither booth gives completely satisfactory magnetic isolation. The plexiglass screen-room booth offers virtually no attenuation to audio frequencies. The metal booth is appreciably better, and its attenuation is great enough to provide a marginally secure magnetic environment, except for leaks around the door. An effective eddy current or magnetic shield must be added to the plexiglass booth since its present screen room contains insufficient metal. Also, magnetic masking noise could easily be achieved by wrapping coils of a few turns each around the outside of the booth, and driving these with an intense, low frequency noise current. (This could be the same noise generator as that for the acoustic masking.) One of these alternatives should be implemented before either booth is used operationally.

Neither the plexiglass nor the metal room was found to be easily inspectable for clandestine devices. Though plexiglass is a clear plastic, the panels of this booth contained opaque structural members which could not be inspected effectively. In addition, seams between panels, plexiglass-plexiglass interfaces, and plexiglass-air interfaces create reflecting and diffracting surfaces which are not inspectable without dismantling the structure. The metal booth is surrounded by an external security shield whose seams are sealed by tape. The entire shield is painted with a special reflecting paint which is difficult if not impossible to match. As they presently exist, the air-conditioning parts and the power panel are not taped, and permit penetration of the shield without violating the special surface. Furthermore, interior panels of the booth can be dismantled easily and equipment can be concealed behind them. Penetrations from the inside permit easy violation of the acoustic and electromagnetic isolation. If either booth is to be used operationally, its walls should be sealed both inside and out with paint or plastic so that violations of its structure can be detected easily.

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Section III. TEST PROCEDURES

1. TEST ENVIRONMENT

Both conference booths were tested in laboratory room No. 15-112 at Murray Hill. The room is a 23-foot-square windowless room with a 12-foot ceiling. Two walls of the room (the west and north) are outside walls of 16-inch-thick masonry, faced on the inside with plaster board on 2-inch furring strips. The other two walls are inside walls, also of 16-inch-thick masonry, but finished with hard plaster surfaces. The room has a hung ceiling about 11 feet below the 16-inch-thick concrete ceiling that is the under side of the roof over the area. The hung ceiling is plaster board attached to a wooden frame. The floor is linoleum on 8-inch-thick concrete and there is no basement beneath the room. The test room was essentially vacant during the tests except for several large file cabinets along the south wall. No additional sound-absorbing material was installed. The laboratory is normally illuminated by 12 two-tube fluorescent fixtures, suspended about 2-1/2 feet from the ceiling. All of the fixtures were used during the tests of the plexiglass booth, but six were removed to permit installation of the metal booth.

2. BOOTH INSTALLATION

The Airtronics plexiglass booth was installed in the test room according to the floor plan shown in Figure 1. Two walls of the booth were two feet from the north and west walls of the laboratory. One of the other two walls of the booth was 5-1/3 feet from the laboratory wall it faced and the other 8-1/6 feet. The booth was supported several inches off the floor, on plexiglass pillars, and access was gained via two plexiglass steps at the door. For the tests, a broadloom rug with no under pad covered all the floor surface. The booth contained no other sound-absorbing material. The circled numbers in Figure 1 represent measurement locations which will be elaborated upon in paragraph 3a.

After the tests were completed on the Airtronics booth it was disassembled and removed. The Ace-Armour metal booth was then installed in the test room as shown in the floor plan of Figure 2. The dimensions of the metal booth differ from those of the plexiglass booth, but the installation was made to permit, as nearly as possible, comparable conditions and locations for measurement. The metal booth was set with its back approximately two feet from the north wall of the laboratory room and its right-hand side approximately three feet from the east wall. This

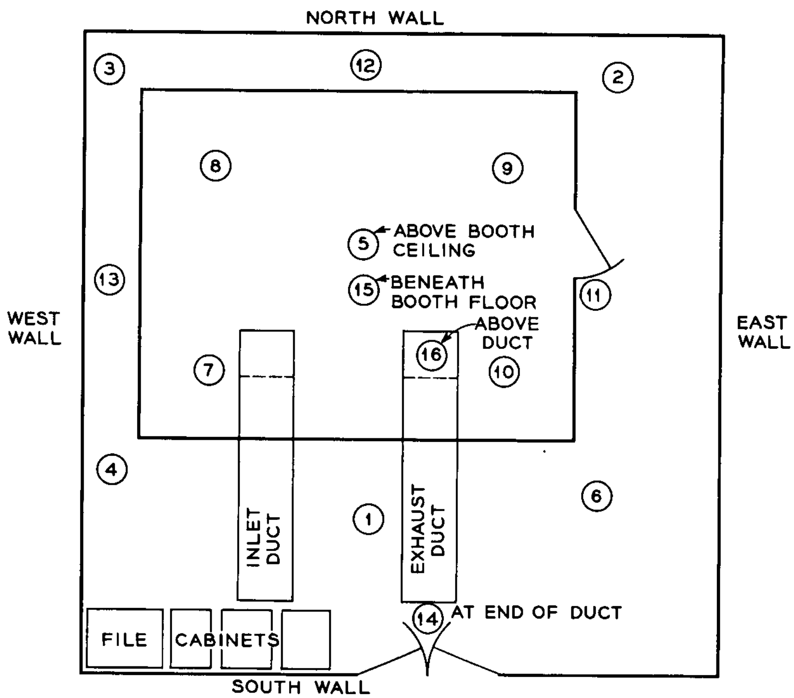

Figure 1. Floor Plan of Installation and Measurement Locations for Plexiglass Booth

left a distance of about nine feet to the west wall and seven feet to the south wall. The metal booth was supported approximately 10 inches off the floor by lucite pillars fitted into shock mounts. As a result, the distance from the booth top to the ceiling of the test room was about 2-1/2 feet. The booth was entered by three wooden steps up to the door. As with the plexiglass booth, a broadloom carpet with no pad covered the floor and no additional sound-absorbing material was used inside.

3. ACOUSTIC MEASUREMENTS

Four types of acoustic measurements were made on both booths. First, the attenuation of the booth structure for octave bands of random noise was measured. Second, the attenuation of the booth for sinusoidal signals, particularly high frequency sine waves, was considered. Third, measurements of the linear displacements of the outer booth wall were made for excitation by a noise sound field inside the booth, and for the same noise field outside. Displacement data were obtained by using a contact pickup (supplied by the Contractor) for which the absolute calibration was known. In the last measurement, articulation tests on standardized recorded speech were made, both for air listening outside the booths, and for contact microphone pickup.

The first two of the acoustic measurements determined, in effect, the sound-level differences between the inside and the outside of the booths. This figure differs in a predictable way from the conventional laboratory measurement of transmission loss (TL). For the present test environment, the difference is relatively small at medium to low frequencies; this will be discussed in some detail in a later section. The acoustic properties of the outside or "parent" room will also be considered.

a. Octave Band Measurements with Random Noise

A random noise generator (General Radio Type 1390) supplied white noise, spectrum flat to 20 kc, to a good quality, 40-watt power amplifier (Scott Type 250 AR). The amplifier drove a wide-range loudspeaker situated in a corner inside the booth. In the case of the plexiglass booth, the speaker was a 12-inch Western Electric Type 754 in a 6-cubic-foot box. For the metal booth, more acoustic power was required, and an Altec "Voice of the Theater" tweeter-woofer combination was used. The noise fields inside and outside the booths were analyzed over the frequency range 20 to 10,000 cps with a General Radio Type 1551 Sound Level Meter (SLM) connected to a General Radio Type 1550 Octave Band Analyzer (OBA). This apparatus provides absolute readings of the over-all rms sound pressure in db re 0.0002 dyne/cm^2, and the rms sound pressure level (spl) in octave filter bands. The octave bands, and their geometric mean frequencies (at which all of our data are plotted), are:

Band (cps)	Geometric Mean Frequency (cps)
20-75	39
75-150	106
150-300	212
300-600	424
600-1200	847
1200-2400	1695
2400-4800	3390
4800-10,000	6930

The noise fields produced inside the booths were relatively uniform throughout the enclosures. They were measured at several points, however, and the octave band values averaged to arrive at a mean source specification. Level differences at various outside points were obtained by subtracting the outside readings from the mean levels inside.

Octave band measurements were made at all the locations designated by the circled numbers in Figures 1 and 2. If each booth is viewed from the side with the door, and if this side is called the front, then the measurement locations can be described approximately as:

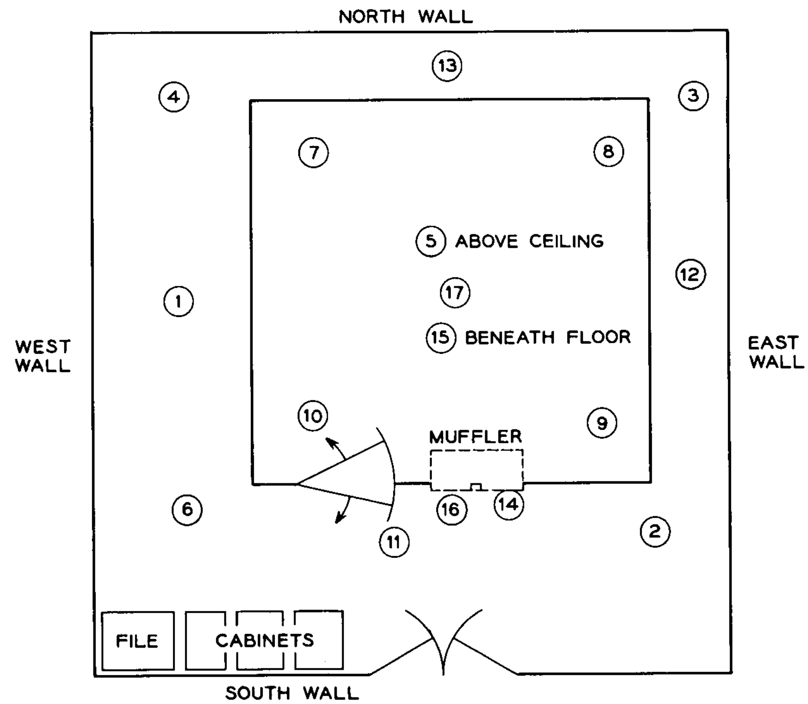

Figure 2. Floor Plan of Installation and Measurement Locations for Metal Booth

1. Three feet from the center of the left wall
2. Three feet from the front, right corner
3. Two feet diagonally from the back, right corner
4. Two feet diagonally from the back, left corner
5. One foot above the center of the booth ceiling
6. Three feet diagonally from the front, left corner
7. Inside back, left corner, three feet from the walls
8. Inside back, right corner, three feet from the walls
9. Inside front, right corner, three feet from the walls (not accessible in metal booth because large loudspeaker occupied this position)
10. Inside front, left corner, three feet from the walls
11. Door seal, swing side
12. One foot from the center of the right wall
13. One foot from the center of the back wall
14. Three inches from the air duct (lower duct in metal booth)

15. Beneath booth floor

16. Three inches from the air duct (upper duct in metal booth)

17. Inside, center.

b. Sine Wave Measurements

Two types of sine wave measurements were made: one over a high frequency range from 5 to 100 kc; and another over a small range of low audio frequencies. The former were to extend the attenuation measurements into the ultra-audible range; the latter were mainly to check the octave band noise results.

An Electro-Voice Model T-3500 "Ionovac" loudspeaker was used as the high frequency sound source. This loudspeaker radiates sound from a modulated corona discharge of cylindrical symmetry. It responds well into the ultrasonic range, though its output falls off at frequencies above 30 kc. A Western Electric Model 640AA condenser microphone was used as the receiver. The sensitivity of this microphone diminishes at about 12 db/octave at frequencies above 15 kc, but is useful into the ultrasonic range so long as signal-to-noise ratio permits. At 100 kc, for example, the combined response of the speaker and microphone was down 60 db from its value at 5 kc.

The arrangement of the apparatus for making the high frequency measurements is shown in Figure 3. An R-C oscillator supplied the input to the loudspeaker, and an amplifier and high frequency wave analyzer received the output of the microphone. The Ionovac speaker was set up inside the booth, three feet from the wall, on an axis perpendicular to the wall. The response of the over-all system was measured first with the 640AA microphone located two feet from the speaker and

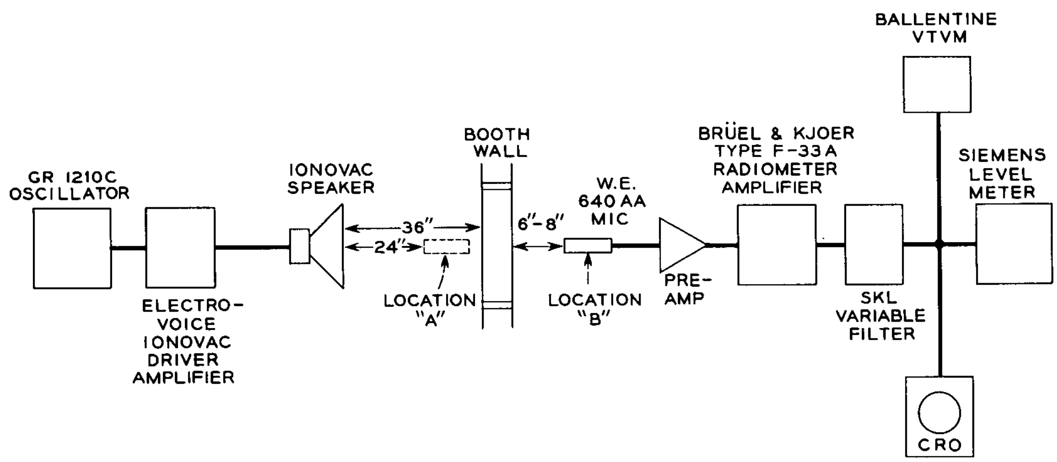

Figure 3. Arrangement of Apparatus for Measuring Acoustic Attenuation of Booth at High Frequencies

one foot from the inside wall (location "A" in Figure 3). The microphone was then placed outside the booth about one-half foot from the wall at the irradiated point and, with the same voltages applied to the inside source, the outside levels were measured. During the measurements, the position of the microphone was moved over an area of a few square inches to obtain the greatest signal pickup in each case. Consequently, the measured pressure level differences are conservative and represent near minimum values.

Because of limitations of power output of the loudspeaker, sensitivity of the microphone, ambient room noise, and electrical circuit noise, it was not possible to measure outside signals at frequencies higher than about 30 kc (slightly lower for the metal booth, slightly higher for the plexiglass booth). The limiting noise level could be measured at frequencies higher than this, however, so lower bounds to the level difference could be specified for frequencies up to about 100 kc.

The low frequency audio sine waves were generated by using an oscillator (General Radio Model 1304B) to feed the audio equipment described in paragraph 3a. Standing waves inside the booth were minimized by frequency modulating (warbling) the oscillator ±25 cps at two per second (with a General Radio Type 1750 Sweep Drive). The outside sound level measurements were made with the previously described audio equipment.

c. Contact Microphone Measurements

A dual-channel contact microphone kit, complete with preamplifier and other accessories, was provided by the Contractor. This set, the absolute calibration of which was known, was used to determine wall vibration for a given sound pressure inside the booth. In addition, it was used to determine the intelligibility of structure-borne sound at the outer wall of the booth. The outer wall displacement was determined for excitation by a noise field inside the booth, and for the same field outside the booth. For both rooms, the spectrum level of wall displacement was computed for the source spectrum corrected to a flat spectrum of 55 db/cycle. The contact pickup data for inside and outside excitation were also used to deduce the optimum external masking of the contact pickup.

d. Articulation Tests

Speech intelligibility tests were performed on both booths to determine the extent to which speech sounds are available for external air and contact pickup. External noise levels necessary to mask both the air and contact signals were determined in the tests. Because of the important uses proposed for the conference booths it was felt that the intelligibility tests should be conservative and stringent, as well as sensitive, measures. For this reason a source speech level which is about as loud as would ever be encountered in practice inside the booth was used.

The over-all rms speech level was measured on the sound level meter (SLM) using the "flat" weighting and the "fast" meter response. (The latter position provides ballistic characteristics of the meter which agree with current standards of the ASA.) The level was measured at a distance of one meter from the speaker but, because both booths are very "live," the speech level was approximately the same everywhere inside. The speech gain was adjusted so that approximately one-fifth to one-fourth of the speech peaks were as great as, or greater than, 80 db re 0.0002 dyne/cm^2. This level corresponds to a long-time over-all rms value of around 78 db, and is about as loud as a man can speak without changing his mode of voicing (that is, without shouting). In computations of speech intelligibility by the articulation index technique (to be discussed in more detail later), a voice level of about 69 db is used conventionally to describe a raised voice at 1 meter in free space. This is about 9 db softer than the levels used in the present intelligibility tests. It corresponds to a level for which only about one per cent of the rms speech peaks in 1/8-second intervals get as high as, or exceed, 80 db.

Lists of phonetically-balanced (PB) monosyllabic words spoken in a carrier sentence were played from a tape recorder (Magnecord Model PT-6) via a loudspeaker (General Electric Model 1201) placed in a corner inside the booth. A typical utterance was "You will write bask, now." The test items were provided by a total of three speakers (all men), each reading fifty words. Two listeners wrote down the test words they were able to hear through the contact apparatus (dual and single channel) installed on the outer wall of the booth. The same listeners attempted to hear the articulation lists with their unaided ears in the immediate vicinity of the outer wall of the booth. The articulation score was computed as the percentage of the PB test words heard correctly.

As a further check on these tests, computations of speech intelligibility, using the articulation index (AI) technique, were made for both booths. Such computations are possible from a knowledge of the booth attenuations and the ambient, or masking, noise levels.

4. ELECTROMAGNETIC MEASUREMENTS

Radio frequency measurements were made to determine the attenuation of both booths over the frequency range 12 mc to 10,000 mc. Measurements were made at the discrete frequencies 12, 30, 34, 200, 900, and 10,000 mc for the plexiglass booth, and at 30, 49, 205, 975, and 10,000 mc for the metal booth. The sources used to generate the frequencies were a General Radio Model 1218A up to 50 mc, a General Radio Model 1209BL for the 200-mc point, and a General Radio Model 1001A for the 900-mc point. The receiver used for all these frequencies was an Empire Devices Model NF 105. The apparatus for the 10,000-mc measurement is shown in Figure 4.

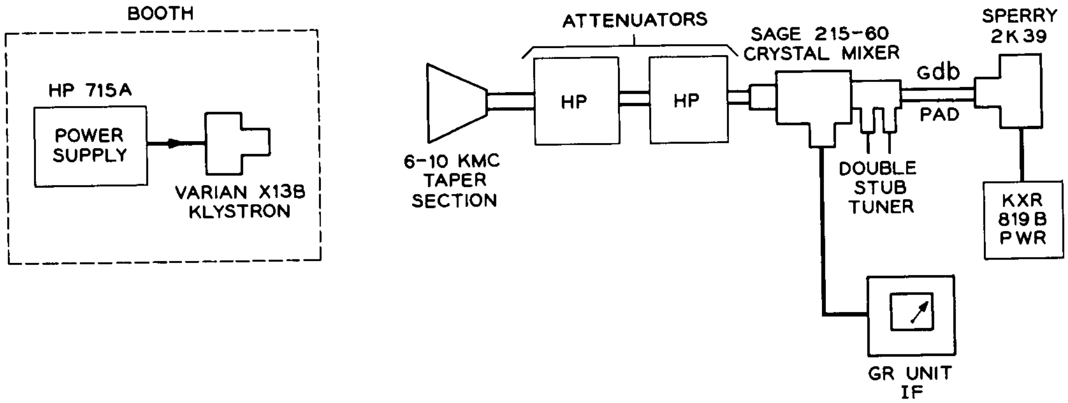

Figure 4. Block Diagram for the 10,000-mc Measurements

For all except the highest frequency, the measurement procedure was as follows. A dipole radiator was set up inside the booth and the door was opened its full width. The receiver probe was placed two feet away from the door, and the transmitting antenna was rotated until maximum signal was received. At low frequencies, where strong standing wave patterns were observed, the frequency was adjusted for a current minimum at the terminals of the signal generator. The door was then closed, and the position of the maximum field outside the booth was determined. The radiator was then readjusted to maximize the external field. All readings were made at points two feet from the booth walls.

For the 10,000-mc source, a similar measurement was made through the open door. The source was then directed at various points inside the room susceptible of r-f transmission, and the receiving horn was used to search the exterior of the booth.

5. MAGNETIC FIELD MEASUREMENTS

Transmission of audio-frequency signals by means of coupling to magnetic fields is feasible over distances of some tens of feet with modest power requirements of only a few watts in the transmitter. A very-low-power system was therefore devised to test the effectiveness of the plexiglass booth in attenuating audio-frequency magnetic fields.

A transistorized circuit was made up as shown in Figure 5. The radiating coil at the transmitter output consisted of 1200 turns of No. 33 gauge enameled wire on a 3-inch circular form. Its total inductance at 1000 cycles was 0.18 henry. The Shure MC-11-J microphone used in this test is a variable reluctance type. With the circuit gain control set on maximum, the speech signals across the output coil measured 14 volts when loud speech was applied to the microphone. The output push-pull 2N188A stage operated as a class B amplifier. The maximum total battery power drawn from the 10-volt battery by all three stages was 100 milliwatts.

For the receiver, a single-layer solenoid wound around a ferrite rod was used as the pickup device; this was connected directly to the input of a General Radio 1550A Octave Band Analyzer. The single-layer winding had 4100 turns of No. 38 gauge wire; its inductance at 1000 cycles was 1.4 henries.

The effectiveness of the plexiglass booth was found by using these sending and receiving coils to measure the received signal outside the booth when the transmitter was first inside and then outside. A further test was made with the sending coil located outside the west wall of the booth, and the receiving coil outside the east wall. For this condition, the path between the two coils passed through two complete walls of the booth. The ambient noise in the measurement location was caused mainly by the magnetic fields about the fluorescent lighting fixtures, and some attention had to be paid to the orientation of the pickup coil for minimum interference from those sources during the test.

This magnetic apparatus was not used for the tests on the metal booth. The attenuation properties of the latter to audio magnetic fields were measured in essentially the same manner, but a 40-watt Scott power amplifier (identical to the one used in the acoustic tests) was used to drive a coil of bell wire which acted as the magnetic source.

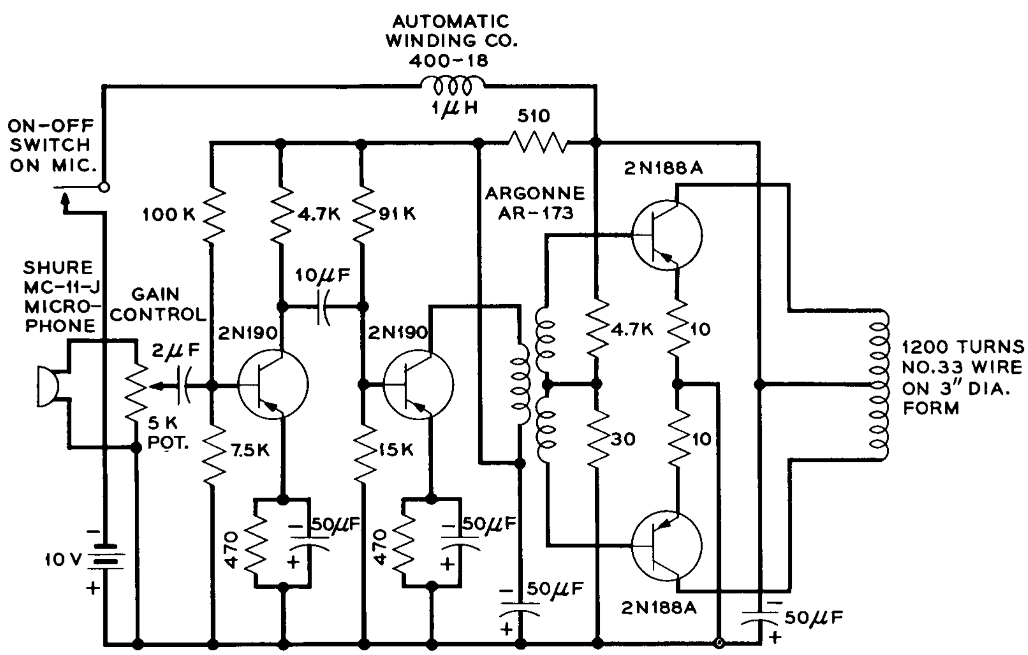

Figure 5. Circuit Diagram for the Magnetic Transmitter

Section IV. RESULTS FOR THE AIRTRONICS PLEXIGLASS BOOTH

1. ACOUSTIC RESULTS

a. Octave Band Noise Measurements

The data from the octave band noise measurements are plotted in Figures 6 through 11. The top curve in Figure 6 shows the level of the noise field inside the booth averaged over the four corner locations. This inside intensity was used for all the octave band noise measurements. Each plotted point is the absolute rms sound pressure level in an octave band (given in db re 0.0002 dyne/cm^2). Each datum point is plotted at the geometric mean frequency of its octave band. (The octave band frequencies have been stated in Section III, paragraph 3a.) If the spectral density of the noise radiated inside the booth were completely uniform (flat spectrum), the octave band levels should increase at 3 db/octave because the bandwidth and noise power double with each higher octave. It can be seen, therefore, that the noise spectrum inside the booth was slightly less than uniform at the very low and high ends. The over-all rms sound pressure of the field inside was 88 db re 0.0002 dyne/cm^2.

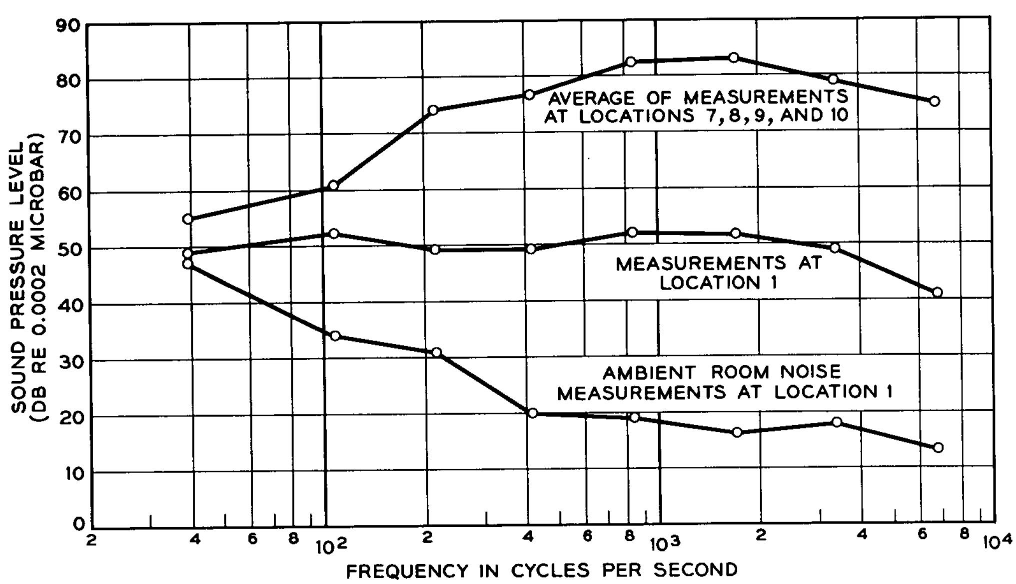

Figure 6. Octave Band Noise Levels for Plexiglass Booth

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The middle curve in Figure 6 gives the rms octave band levels measured at location 1 outside the booth (three feet from center of left wall, looking at door). The differences between the top and middle curves are the level differences for location 1. This figure is indicative of the attenuation incurred by the booth wall and is closely related to the transmission loss for the structure. Most of the remaining data will be presented in terms of level differences. The lower curve in Figure 6 shows the ambient noise at location 1 when the noise source inside the booth is turned off. This noise level is typical of other locations in the room. The difference between the lower two curves is the signal-to-noise ratio (S/N) for the measurement. It can be seen that over the midrange of frequencies the S/N is of the order of 30 db.

The sound pressure level differences for location 1 are plotted in Figure 7. It can be seen that in the midrange of speech frequencies the booth provides an attenuation of the order of 25 to 30 db. As a check on the octave band measurements, the level differences for sine wave excitation inside the booth are also shown at the low frequency end. While the two sets of data agree reasonably well, there are two main reasons why they do not agree exactly. At the low frequencies, standing wave patterns are easily excited inside the room, and it is difficult to obtain a uniform distribution of sound pressure. Also, the attenuation of the booth structure increases essentially monotonically with frequency. The sound energy measured in any octave band outside is mainly contributed by the frequencies close to the lower edge of the band. For comparison with sine wave measurements, therefore, it would be more realistic to plot the octave band level differences at the lower cutoff frequency of the octave band, rather than at the geometric mean frequency.

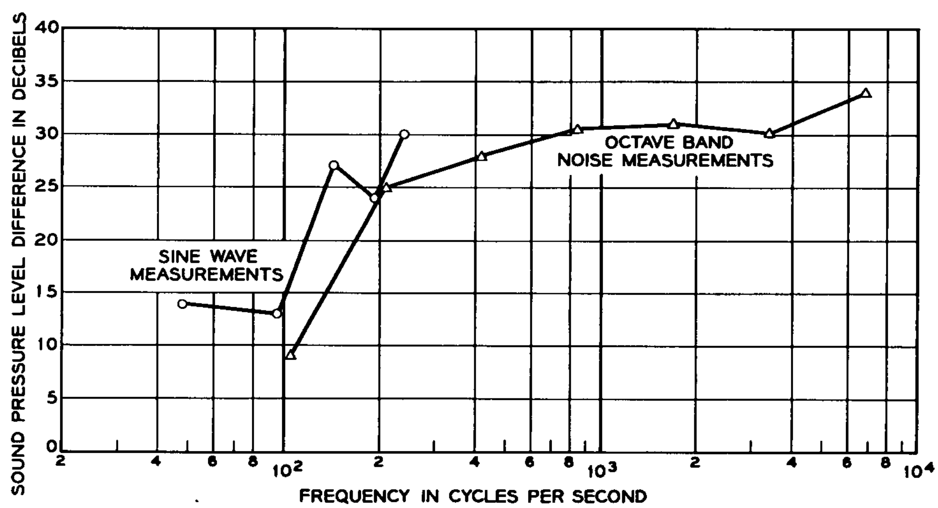

Figure 7. Sound Pressure Level Differences in Octave Bands for Plexiglass Booth — Location 1

The octave band level differences measured at the other locations are plotted in Figures 8 through 11. It can be seen that for the most part the data for the various locations are similar, suggesting that no single part of the structure is worse than any other. A notable exception is the curve in Figure 11 for location 15 (beneath the floor). Here the low frequency attenuation is substantially worse than at other locations. This result is probably due to the close spacing of the duralu-minum grid members in the floor panels. The measurements around the door seals and above the ceiling gave results comparable to those near the side walls. The measurement at the outer end of the ventilator silencer (position 14) shows that leakage through it is less than through the wall or ceiling panels at frequencies above about 1000 cps, and is about the same below 1000 cps.

b. Results of Sine Wave Measurements

The results of the high frequency sine wave measurements (5 to 100 kc) are shown in Figures 12 and 13. The top curve in Figure 12 is the response of the measuring apparatus to the high frequency sound field produced inside the booth by the Ionovac loudspeaker. It reflects the response of the source and the sensitivity of the microphone, and is measured at location "A" in Figure 3. The reference in decibels for the ordinate is arbitrary and is determined by the amplifier and wave analyzer gains. For the same source power, the relative sound levels measured outside the booth at location 12 are shown by the lower curve. It can be seen that the outside level approaches the noise level of the measuring system at a frequency of 34 kc.

The high frequency level difference for location 12 is plotted as the solid curve in Figure 13. Because the outside signal level is less than the system noise level for frequencies greater than 34 kc, the booth attenuation cannot be exactly specified for higher frequencies. It must, however, be at least as great as the dif-ference between the top curve of Figure 12 and the indicated noise level. This dif-erence is therefore a lower bound of the level difference and is shown dashed in Figure 13. From anything that can be conjectured about the leakage of sound from the booth, it would be safe to assume that the solid curve of Figure 13 would con-tinue to rise at frequencies above 34 kc, without any serious holes in the charac-teristic.

To investigate high frequency leakage through the joints in the panels, a series of spot checks was made with the Ionovac loudspeaker and the 640AA microphone on the opposite sides of a joint in the east wall. Points at 5-kc intervals are shown for this measurement by the dotted curve in Figure 13. Up to 30 kc, the attenuation at a joint appears comparable to that in the middle of a clear area of a panel. Here again it is safe to assume from a knowledge of the type of construction, and from

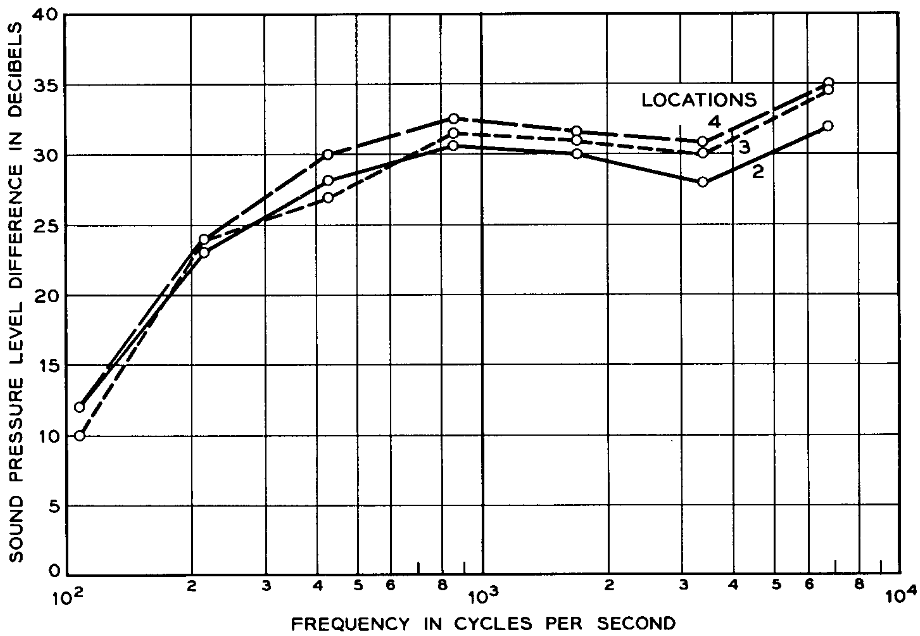

Figure 8. Sound Pressure Level Differences in Octave Bands for Plexiglass Booth — Locations 2, 3, and 4

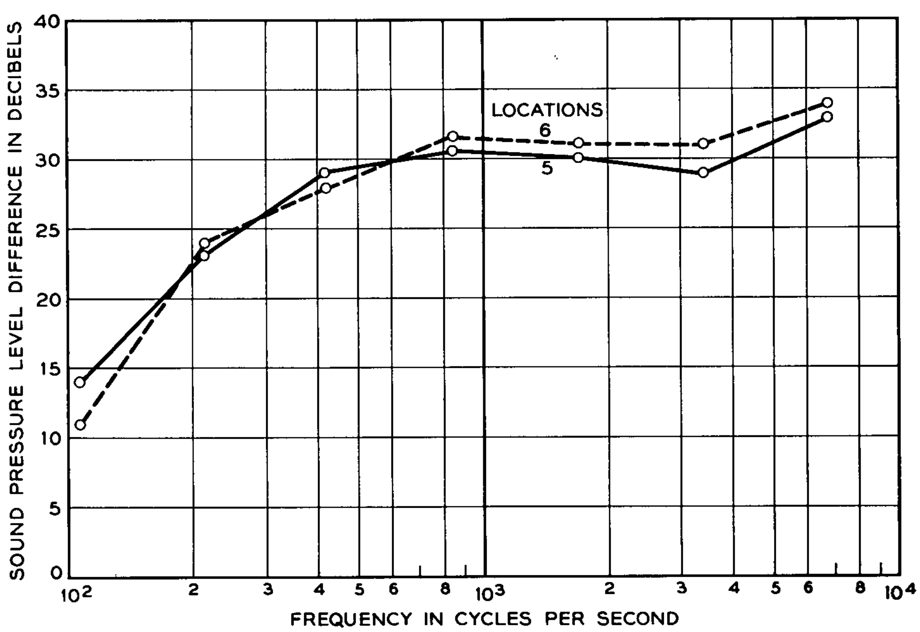

Figure 9. Sound Pressure Level Differences in Octave Bands for Plexiglass Booth — Locations 5 and 6

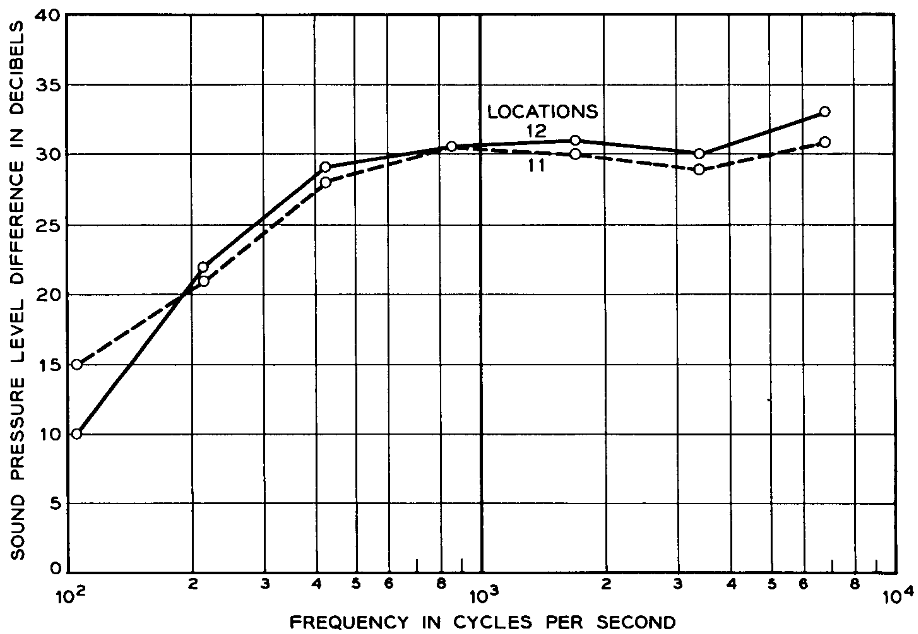

Figure 10. Sound Pressure Level Differences in Octave Bands for Plexiglass Booth — Locations 11 and 12

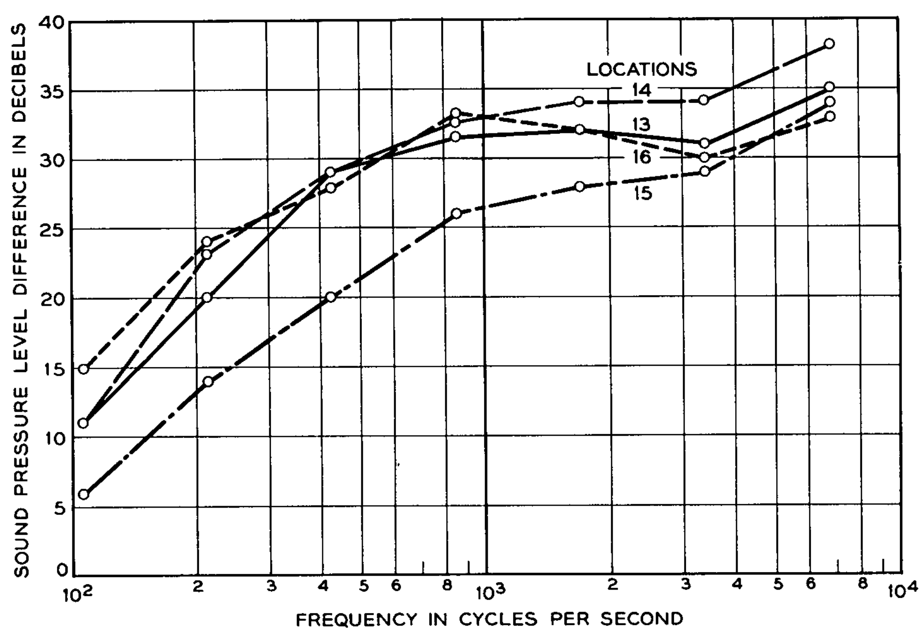

Figure 11. Sound Pressure Level Differences in Octave Bands for Plexiglass Booth — Locations 13, 14, 15, and 16

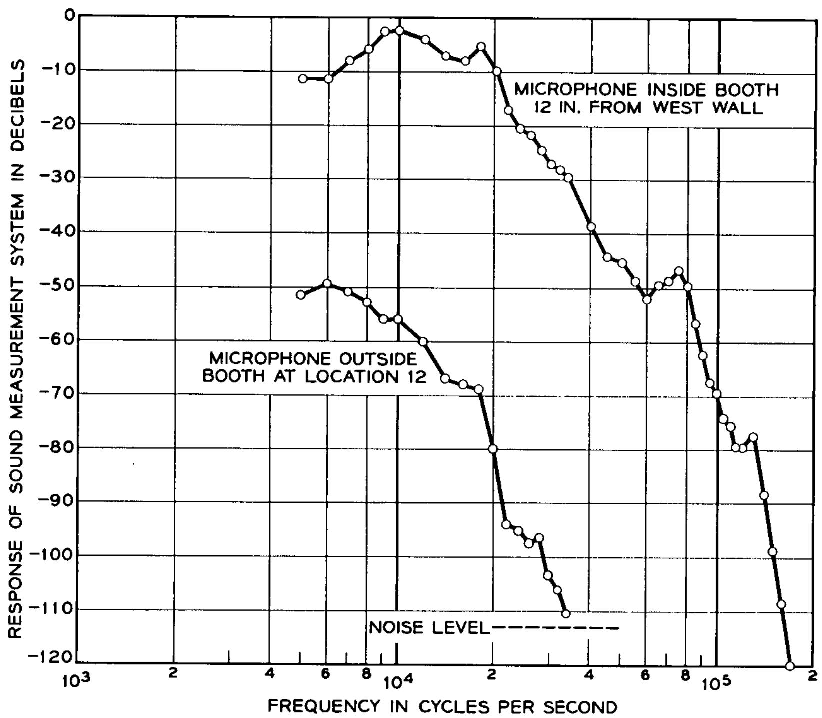

Figure 12. Relative Levels of High Frequency Sine Waves for Plexiglass Booth

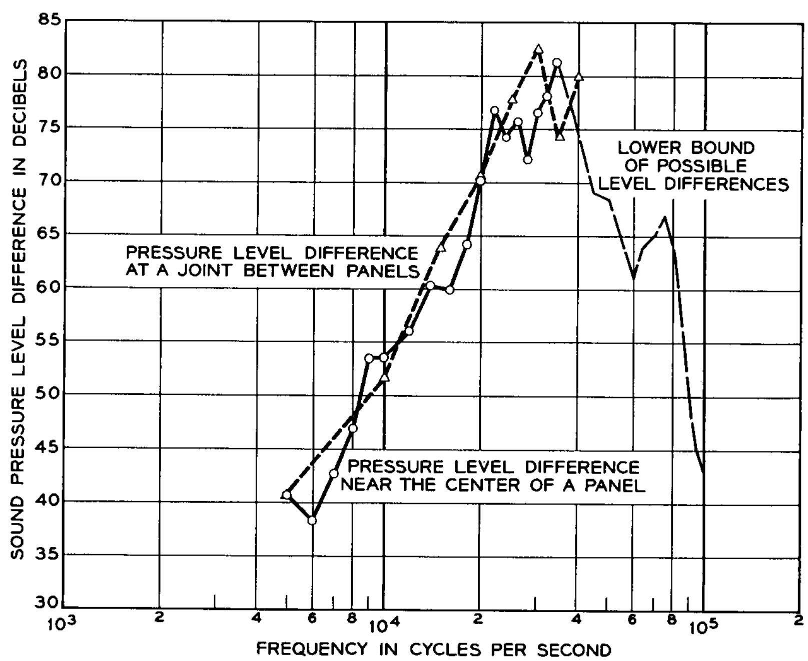

Figure 13. High Frequency Level Differences for Plexiglass Booth

the measurements below 30 kc, that no serious holes would exist in the characteristic between 30 and 100 kc.

The results of the low frequency (50 to 250 cps) sine wave measurements have already been presented in Figure 7 for comparison with the octave band measurements.

c. Results of Contact Microphone Tests

The absolute displacement of the outer walls of the booth, produced by noise fields inside and outside, was determined by measuring the output of the microphone preamplifier in octave bands and applying to this the absolute calibration of the contact transducer. Because of substantial fluctuations in the frequency response of the transducer, the computed wall displacements are approximate. The absolute rms amplitude of displacement per cycle (i.e., spectrum level), measured at a braced point on a wall panel, is shown in Figure 14. These displacement data are for a flat noise excitation in which the spectrum level is 55 db.

It can be seen that the displacement amplitude for inside excitation diminishes roughly at about 15 to 20 db/octave. For the excitation levels used, the ratio of signal to ambient noise for the contact microphone output was about 20 db over the midaudio-frequency range. Because the response of the contact device changes very rapidly at low frequencies, displacements for frequencies of less than 600 cps are not shown. The differences in the octave band levels of the contact pickup for inside and outside noise excitation of the wall is shown in Figure 15. These data will be useful in finding an optimum external noise for masking the contact pickup.

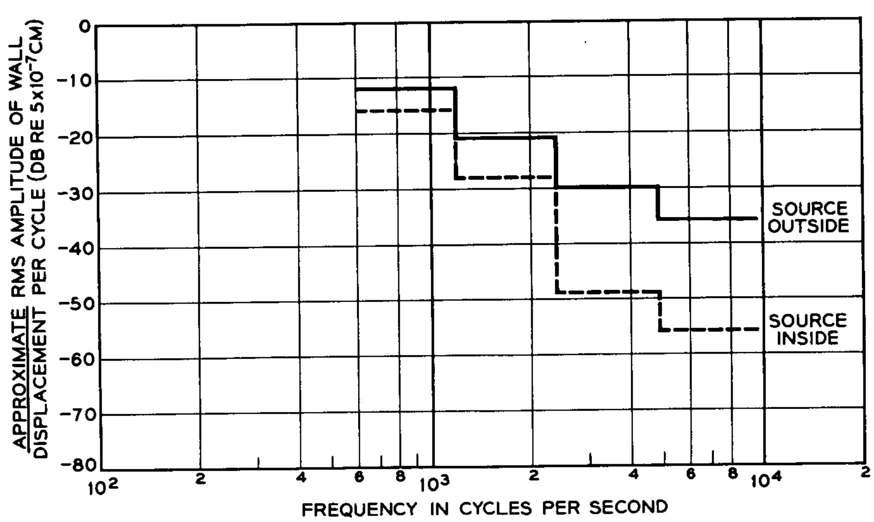

Figure 14. Spectrum Level of Wall Displacement (i.e., rms Displacement per Cycle) for Flat Noise Excitation

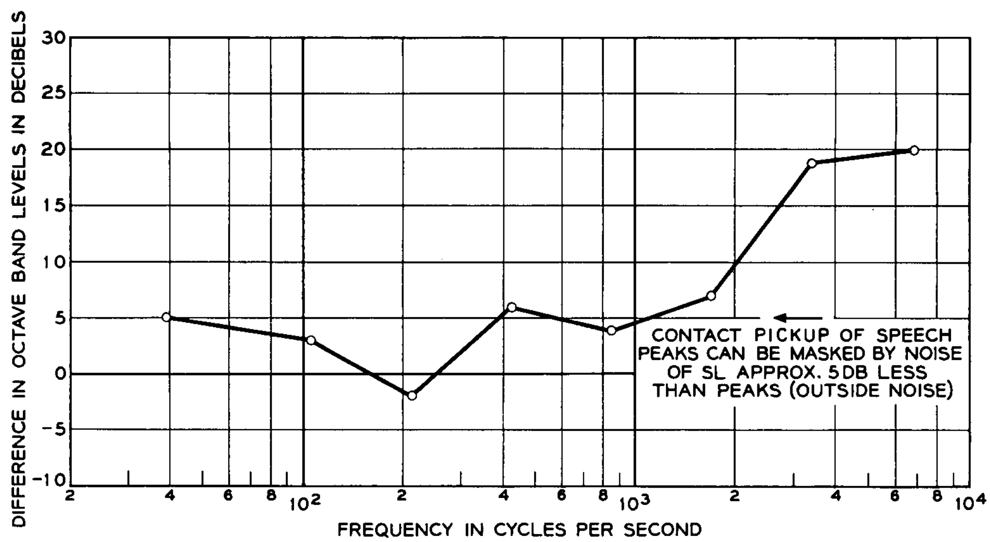

Figure 15. Difference in the Octave Band Levels of Contact Microphone Output for Inside and Outside Noise Excitation of the Walls

d. Speech Intelligibility Results

The results of the PB word articulation tests for air listening outside the plexiglass booth are shown in Table V. The entries in Table V show the number of test words heard correctly out of each 50 presented. As previously stated, the over-all rms speech level inside the booth was about 78 db. The ambient noise outside the booth for this test was not that which has been previously given for the octave band noise measurements but was somewhat higher.[4] For these measurements the external ambient noise in octave bands was:

Band (cps)	Level (db re 0.0002 dyne/cm^2)
20-10K	64
20-75	64
75-150	50
150-300	41
300-600	40
600-1200	34
1200-2400	33
2400-4800	26
4800-10K	31

[4]These tests were conducted at the State Department installation in Washington. Because of the larger and more absorptive parent room, the level differences measured there were greater at the higher frequencies than those shown in Figures 8 through 11. This point is considered further in Section VI.

Table V

ARTICULATION SCORES FOR AIR LISTENING WITH AMBIENT MASKING (PLEXIGLASS BOOTH)*

(Number of PB Words Correct out of 50; Over-all Level of Source Speech = 78 db)

	Speaker		
Listener	NG	GH	JF
HMcD	19	16	16
JF	28	22	13

*Tests made at State Department installation.

From Table V, it can be seen that the articulation scores ranged from 26 to 56 per cent, depending upon talker and listener. For this same ambient noise condition, the word intelligibility dropped essentially to zero when the average speech level inside the booth was reduced by a factor of 10 db; i.e., to about 68 db over all.

The intelligibility of speech sounds which have passed through the booth structure, and have been attenuated by it, can be estimated from a calculation of the articulation index (AI). This technique for computing intelligibility is based upon spectral relations determined by French and Steinberg[5] and extended by Beranek.[6] The method assumes that only those parts of the speech spectrum lying above the threshold of audibility and below the point of overload of the ear, and which are not "covered" by masking noise, contribute to speech intelligibility.

Briefly, it turns out that if the spectrum levels of the speech (i.e., the sound pressure levels in 1-cps bands), the masking noise, and the thresholds are plotted on a frequency scale closely related to the pitch (or mel) scale, equal areas of the uncovered speech spectrum contribute equally to intelligibility. If all the speech spectrum between approximately 200 and 6000 cps lies above the threshold, below overload, and is not masked, the AI is defined as unity, or 100 per cent. Gain adjustments and frequency distortions in the communication path, electrical or acoustical, alter the spectrum level of the speech and hence influence the fractional part of the spectrum obscured by noise or threshold.

Using the scheme proposed by Beranek, the effect of the booth on speech of conversational level can be estimated with the help of Figure 16. The two upper

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[5] N. R. French and J. C. Steinberg, "Factors Governing the Intelligibility of Speech Sounds," Acous Soc Am J, 19 (1947), 90-119.

[6] L. L. Beranek, "Design of Speech Communication Systems," Inst Radio Engrs Proc, 65 (1947), 880-890.

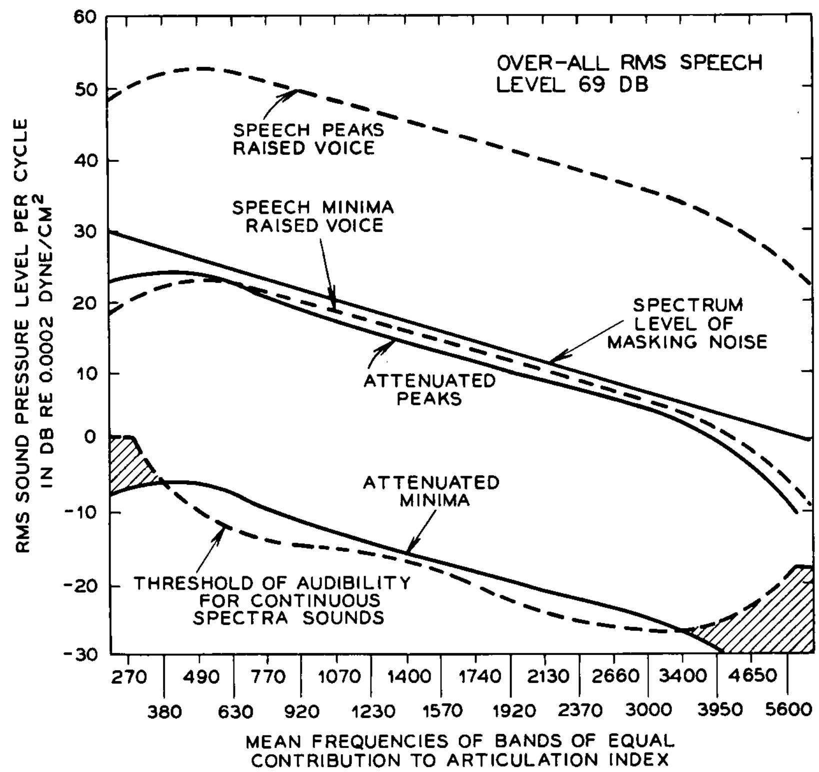

Figure 16. Computation of Speech Intelligibility for the Plexiglass Booth Using the Articulation Index Technique

dashed curves represent the maximum and minimum values of the spectrum levels of speech uttered in a raised voice and measured at a distance of 1 meter in free space (about 69 db over all). The lower dashed curve is the threshold of hearing for continuous spectra sounds. The overload level for the ear is off the top of the graph, and lies at about 95 db. It is the unmasked area between the maximum and minimum curves which contributes linearly to AI.

As an example representative of the performance of the plexiglass booth, consider that the speech spectrum is attenuated according to the level differences measured at location 1 outside the booth (see Figure 7). The levels of the speech peaks and minima are then given by the lower solid curves in Figure 16. If the ambient noise outside the booth is below threshold (a situation which essentially will never be encountered in practice) the booth attenuation results in only a slight encroachment of the threshold curve upon the speech area, i.e., the crosshatched area. The latter is less than one tenth the speech area and consequently the AI for this situation remains of the order of 0.9.

The relationship between AI and intelligibility depends upon a number of parameters and is subject to great variability. Speech material and training of listeners and talkers are among the crucial variables. One relation which is given as a good average for trained listeners and talkers is shown in Figure 17. Completely naive subjects tend to give a more linear relation between AI and intelligibility for monosyllabic words. An AI = 0.9, for instance, represents a relatively high speech intelligibility, in excess of 90 per cent for monosyllabic words. An AI of the order of 0.4 to 0.5 is generally considered adequate for communication.[7]

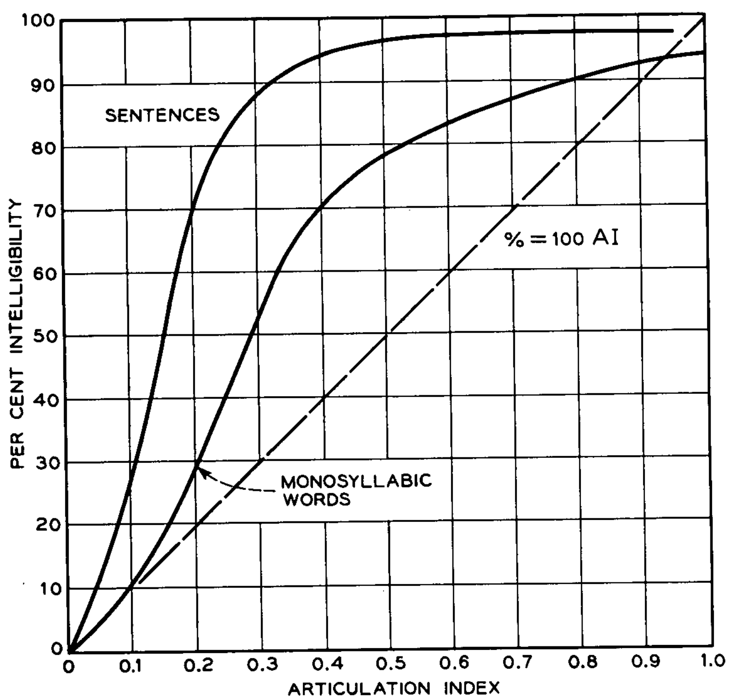

Figure 17. Relation between Articulation Index and Intelligibility

To completely mask the airborne speech sounds at location 1 outside the booth, a noise whose spectrum level is indicated approximately by the sloping straight line in Figure 16 would be required. This spectrum falls off at about -6 to -9 db/octave. The over-all rms sound pressure level of this masking noise can be computed by summing the power per cycle. If, for example, f_1 and f_2 are the lower and upper band limits between which the spectrum slopes at -6 db/octave, and if the spectrum level at f_1 is SL_1, then the over-all level is:

[7] C. Harris (ed.), Handbook of Noise Control, McGraw-Hill Book Company, Inc., New York, 1957.

$$L = SL_1 + 10 \log_{10} f_1 + 10 \log_{10} (\ln f_2/f_1).$$

For the present situation, this gives $L \cong 60$ db re 0.0002 dyne/cm^2. If the masking noise had a flat spectrum, the over-all level necessary for complete masking at location 1 would be $L = SL_1 + 10 \log_{10} (f_2 - f_1)$, or approximately 68 db. It is obvious that if the speech level inside the booth is increased, the level of the masking noise must be increased.

As previously stated, the environmental conditions under which the articulation tests were performed on the plexiglass booth differed from those of the other acoustic measurements (the former being carried out at the State Department installation). However, when the measured level differences (see Section VI for these data) are applied to the 78-db speech source inside the booth, and the ambient noise levels (stated earlier in this section) are plotted, the articulation index diagram appears as shown in Figure 18. For these conditions, the area left exposed above the ambient noise level is roughly one third that of the original "speech area," and the AI is approximately 0.3. Figure 17 shows that this index corresponds to a word intelligibility of about 50 per cent for sophisticated listeners and about 30 per

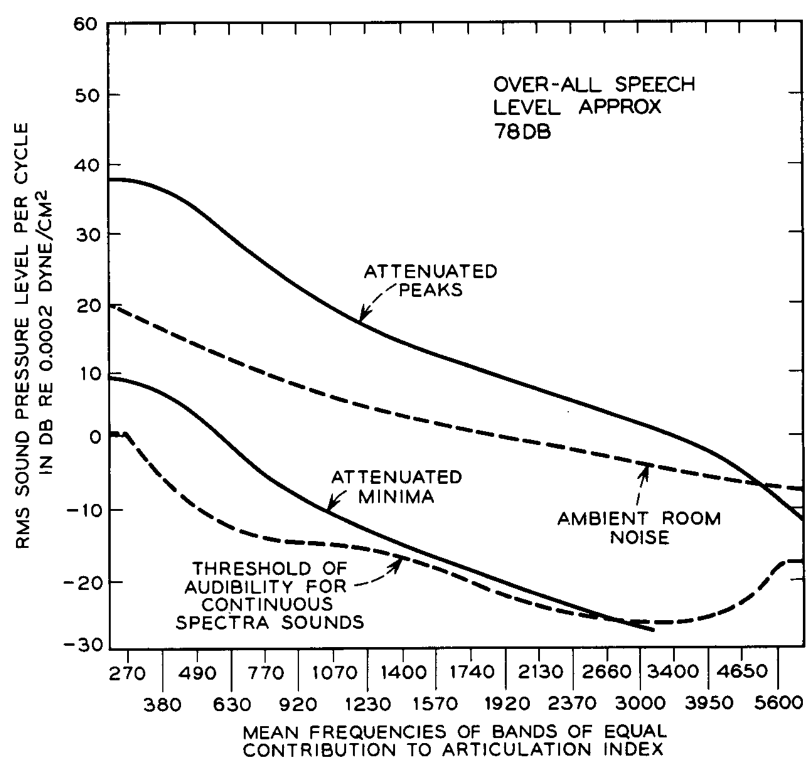

Figure 18. Articulation Index Computation for the Plexiglass Booth for the Conditions Used in the Word Intelligibility Tests

cent for naive listeners. Complete masking of this condition could be achieved by a noise spectrum whose spectrum level at 200 cps is about 45 db and whose shape is roughly -12 db/octave. The over-all level for such a masking spectrum is calculated as 68 db re 0.0002 dyne/cm^2.

In considering noise sources external to the booth for masking the transmitted speech, it must be recognized that the walls transmit bilaterally and that the noise transmitted into the booth may become objectionable after prolonged exposure. The noise level for external masking is not, in the present case, dictated by the airborne signal, but by the signal available for contact pickup, as will become evident from the results to be discussed in the following paragraph.

Similar articulation tests for only one talker were conducted with the contact microphone installed over a structural member on the outside wall of the plexiglass booth. When the pickup was masked by only the external ambient noise of the room, the reception was close to perfect (94 per cent correct) as witnessed by the entries in Table VI. The wall displacement measurements reported in the previous section suggest that the optimum masker for this type of pickup should be a noise whose spectrum is shaped like the speech spectrum but diminished by the amounts shown in Figure 15 (i.e., diminished by the increase in "effectiveness" of the external source in producing outer wall motion). The spectrum level of speech peaks (for 69-db over-all speech) is about 50 db at low frequencies. Since Figure 15 shows that this can be diminished by about 5 db, the asymptotic spectrum sketched on Figure 19 might be taken as a first approximation to the optimum masker for speech at a 69-db level. (Notice the absence of energy below about 200 cps.) Such a spectrum, the over-all level of which is computed to be 76 db, was approximated by appropriately filtering a noise source.

Table VI

ARTICULATION SCORES FOR CONTACT PICKUP WITH AMBIENT MASKING (PLEXIGLASS BOOTH)*

(Number of PB Words Correct Out of 50; Over-all Level of Source Speech = 78 db)

Listener	Speaker: NG
HMcD	47
JF	47

*Tests made at State Department installation.

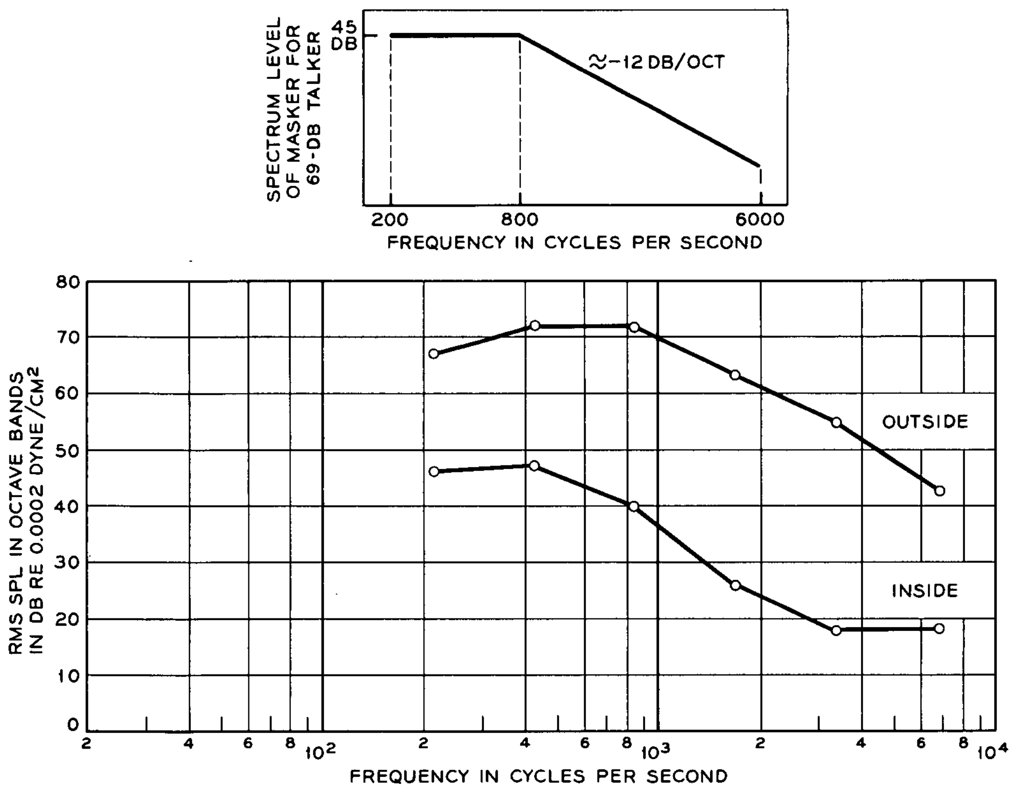

Figure 19. Octave Band Levels of External Noise Used to Mask Contact Pickup on Plexiglass Booth

The actual octave band levels measured for this masker are plotted in Figure 19; its over-all intensity measured 76 db. (The levels produced inside the plexiglass room by this external masker are also plotted in Figure 19.) The resulting word intelligibility for this masking of the contact pickup for 78-db speech ranged from 8 to 14 per cent as shown in Table VII. These scores are near to the threshold of speech intelligibility (defined for connected discourse), the over-all level

Table VII

ARTICULATION SCORES FOR CONTACT PICKUP WITH 76-DB MASKING NOISE (PLEXIGLASS BOOTH)*

(Number of PB Words Correct Out of 50; Over-all Level of Source Speech = 78 db)

Listener	Speaker: GH
HMcD	7
JF	4

*Tests made at State Department installation.

for which is some 5 db or more greater than that for just detecting (but not understanding) the speech in noise. If the 78-db source speech is to be masked so that it is completely undetectable in an external contact pickup, the noise must be increased by some 5 to 9 db for an over-all noise level between 81 to 85 db. Furthermore, if the mask is not spectrally shaped in accordance with the speech spectrum and the data in Figure 15, the available masking power will be less effectively used, and a still higher over-all level will be necessary.

2. ELECTROMAGNETIC RESULTS

The results of the measurements of electromagnetic attenuation, performed in accordance with Section III, paragraph 4, may be tabulated as follows:

Frequency (mc)	"Worst Case" Attenuation (db)
12	53
30	56
34	58
200	68
900	59
10,000 (at air vent)	37
10,000 (except air vent)	64

In all cases, the minimum attenuation occurred in the region proximate to the filter panel and seemed to be a near field effect in that the field strength decreased rapidly with distances. The above figures represent the minimum attenuations.

3. RESULTS OF MAGNETIC FIELD MEASUREMENTS

The brief experiment with the transmission of speech by induction fields showed that as expected the booth, including the shield room, provides virtually no attenuation. The magnetic attenuation provided by the screen booth for frequencies between 15 and 200 kc is shown in Figure 20. These data were supplied by the manufacturer of the shield room. The attenuation value of 4.5 db, found for the frequency range 600 to 1200 cps, appears to agree with an extrapolation of the characteristic in Figure 20. To prevent this sort of transmission at the lower frequencies, heavy shielding with high-permeability magnetic material would be required. Laminated-conductor, eddy-current shielding might be used at higher frequencies. The alternative is sufficient magnetic masking noise.

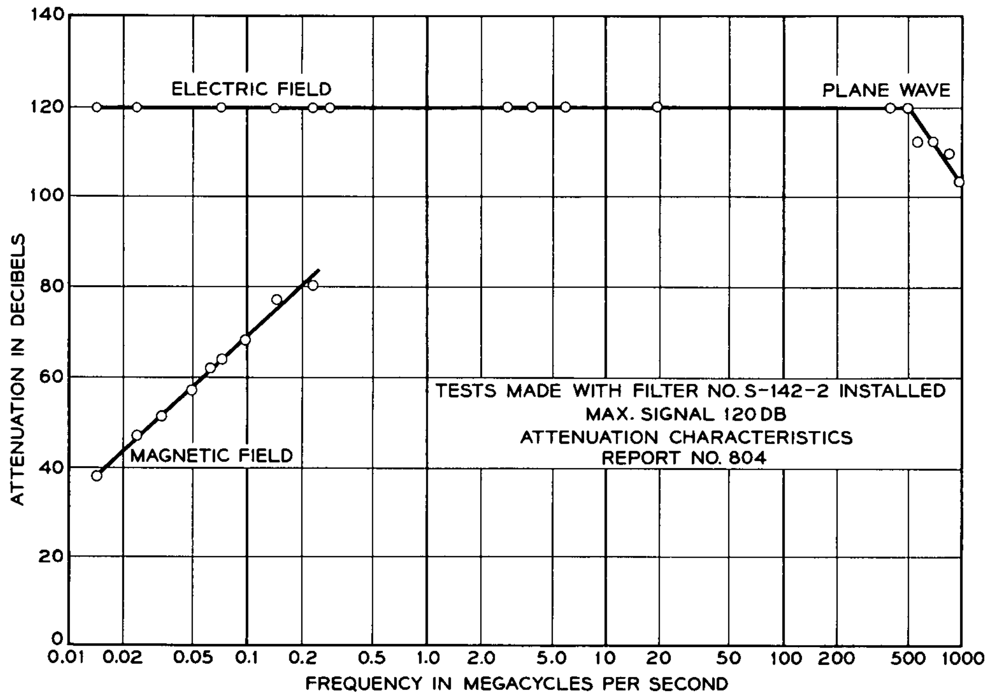

Figure 20. Manufacturer's Data for Screen Room Shielding

Section V. RESULTS FOR THE ACE-ARMOUR METAL BOOTH

1. ACOUSTIC RESULTS

a. Octave Band Noise Measurements

The data from the octave band noise measurements on the metal booth are shown in Figures 21 through 29, and are presented in a manner identical to those of Figures 6 through 11 for the plexiglass booth. The octave band sound levels generated inside the metal booth are shown by the top curve in Figure 21. Points on this curve are spatial averages over three corner and one central locations inside the booth. The inside level generated for the metal booth is approximately 12 db higher than that used for the plexiglass booth, owing to the greater attenuation of the former. The sound pressure levels and ambient room noise measured at location 1 outside the booth are shown by the middle and lower curves, respectively, of Figure 21. The sound pressure level differences for location 1 are plotted in Figure 22, in which the results of the low frequency sine wave measurements are

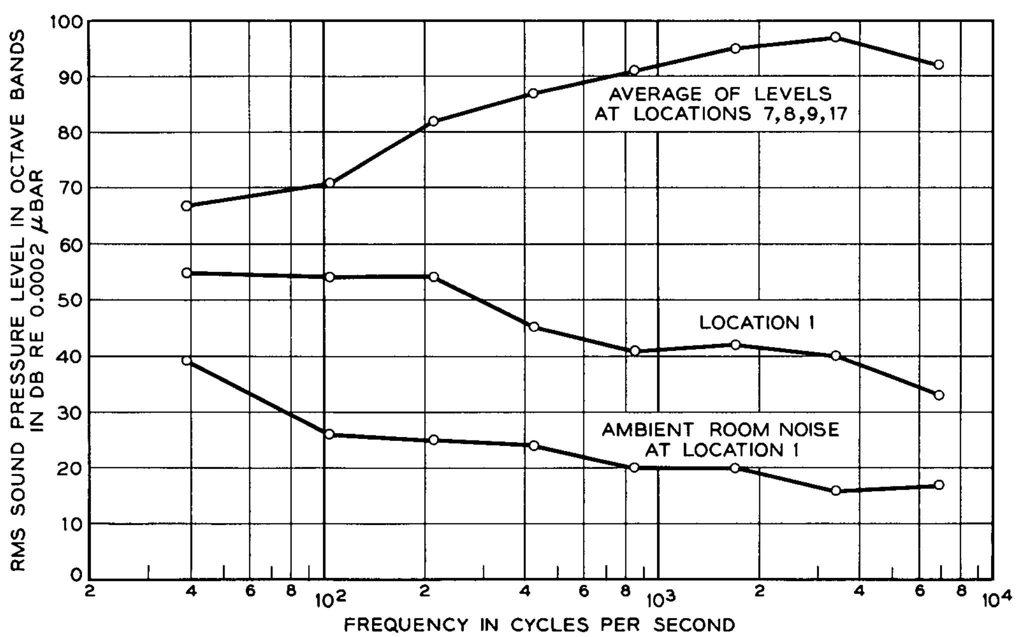

Figure 21. Octave Band Noise Levels for the Metal Booth

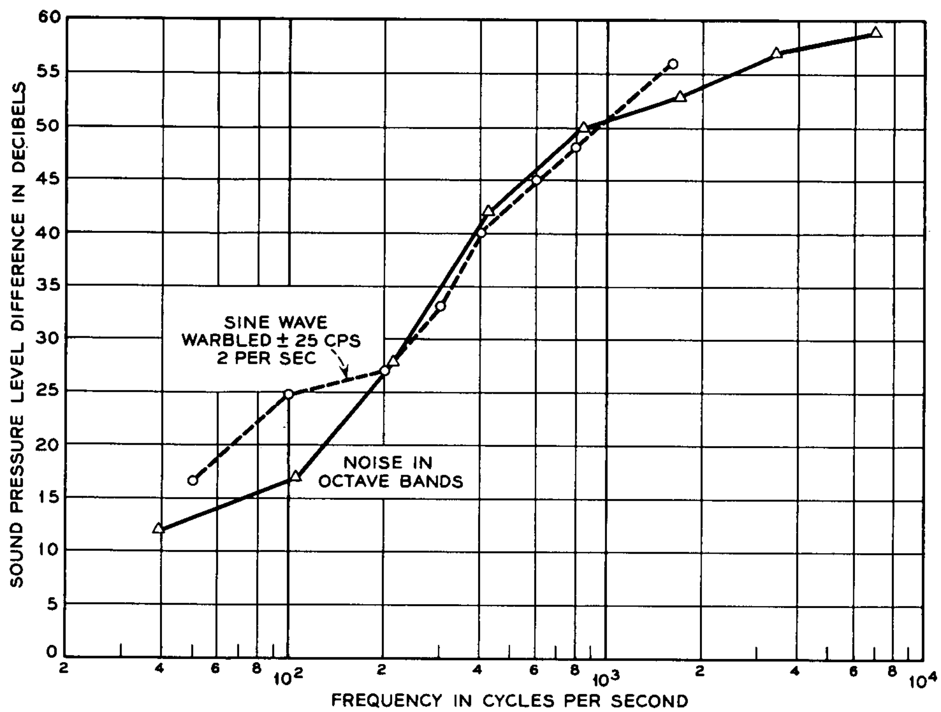

Figure 22. Sound Pressure Level Differences in Octave Bands for the Metal Booth — Location 1

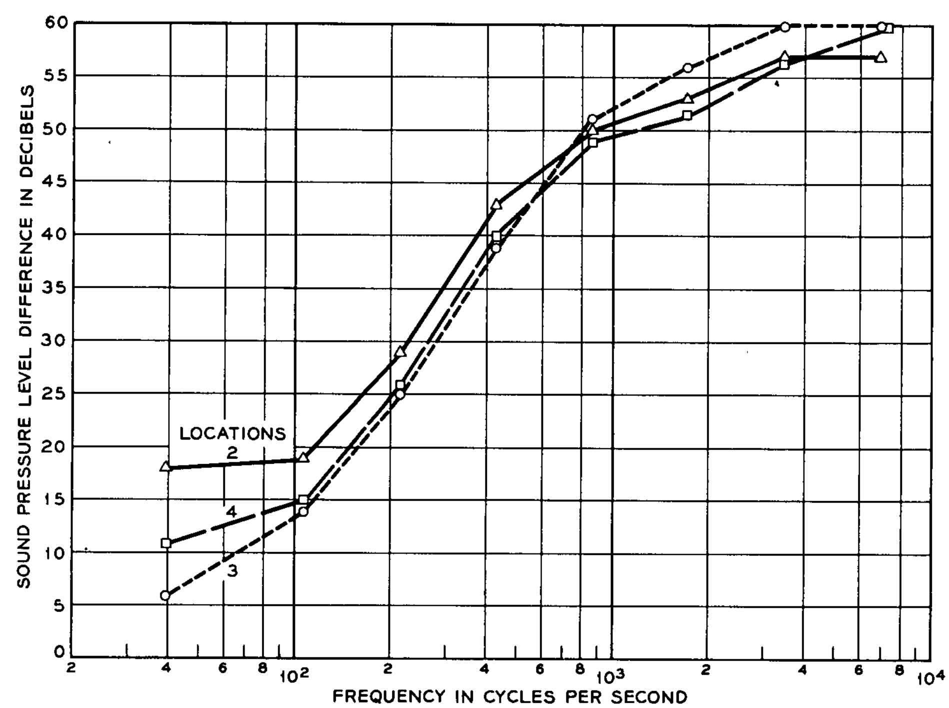

Figure 23. Sound Pressure Level Differences in Octave Bands for the Metal Booth — Locations 2, 3, and 4

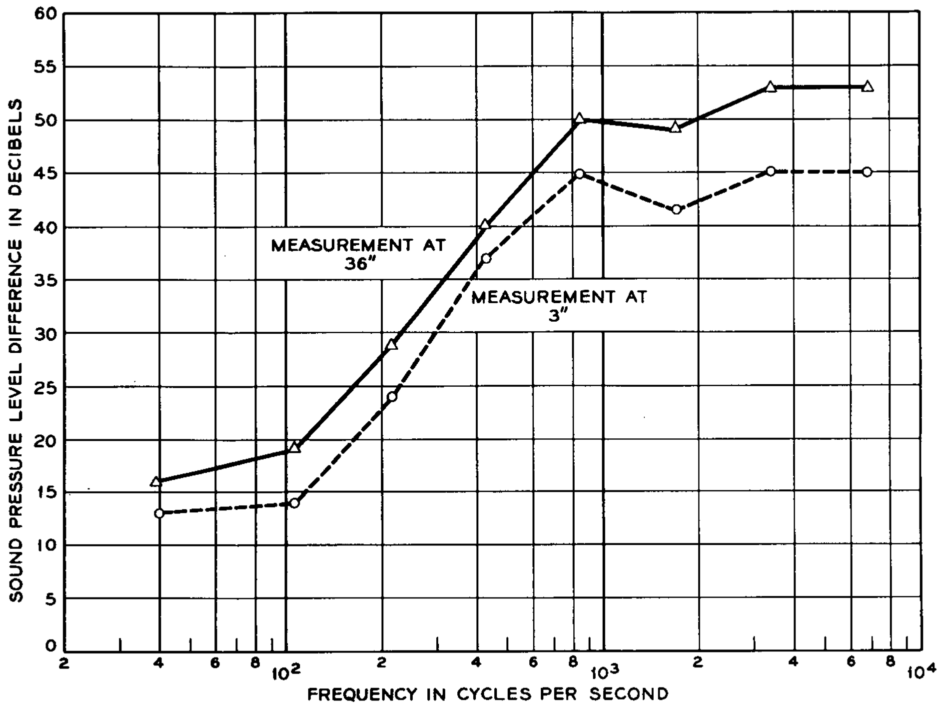

Figure 24. Sound Pressure Level Differences in Octave Bands for the Metal Booth — Location 11

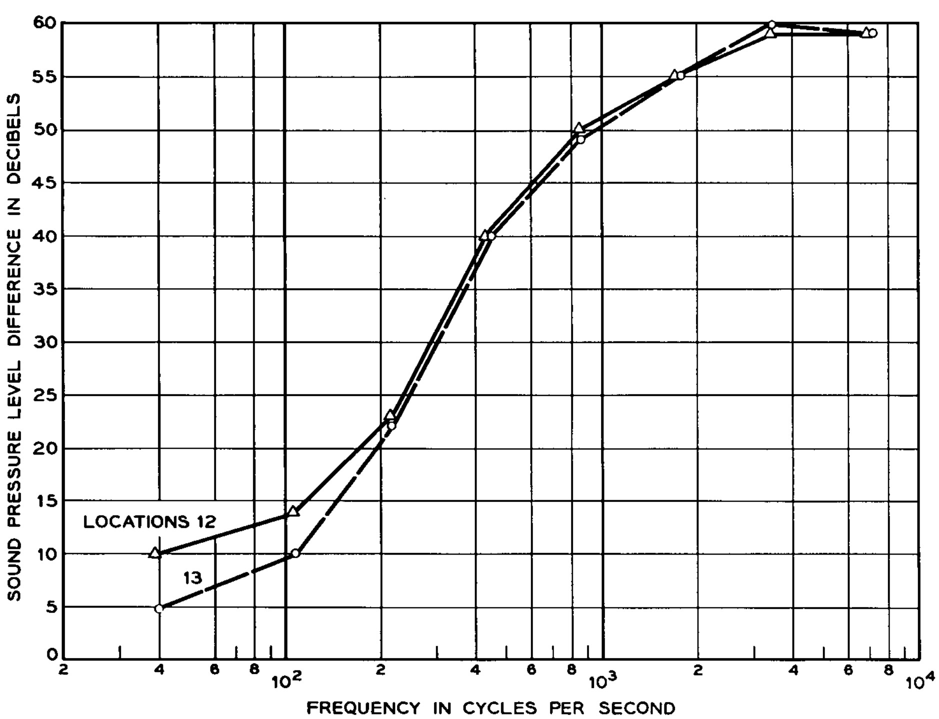

Figure 25. Sound Pressure Level Differences in Octave Bands for the Metal Booth — Locations 12 and 13

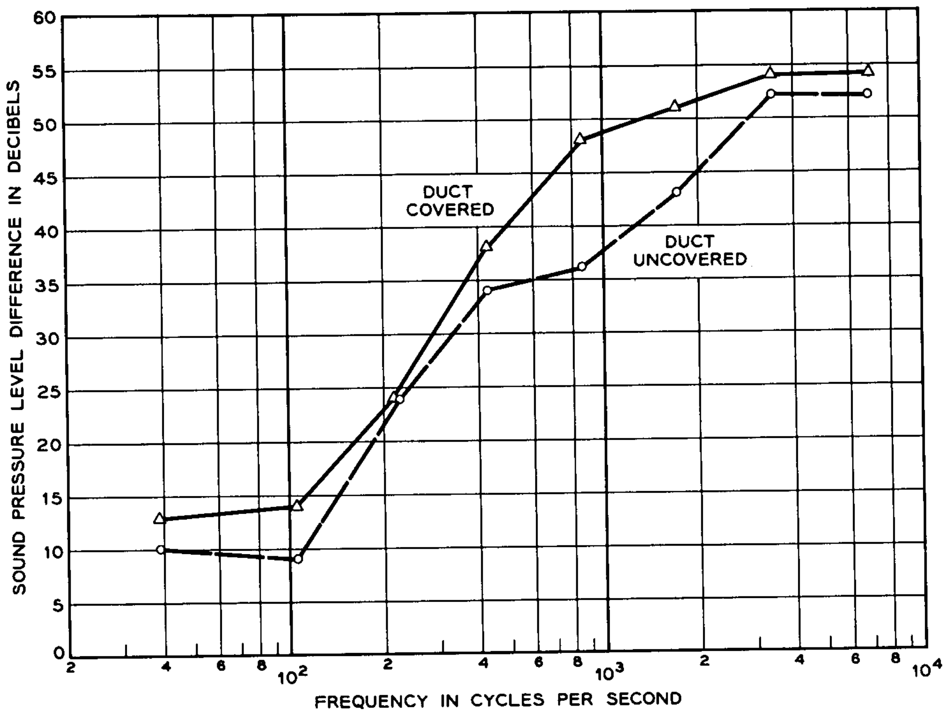

Figure 26. Sound Pressure Level Differences in Octave Bands for the Metal Booth — Location 14

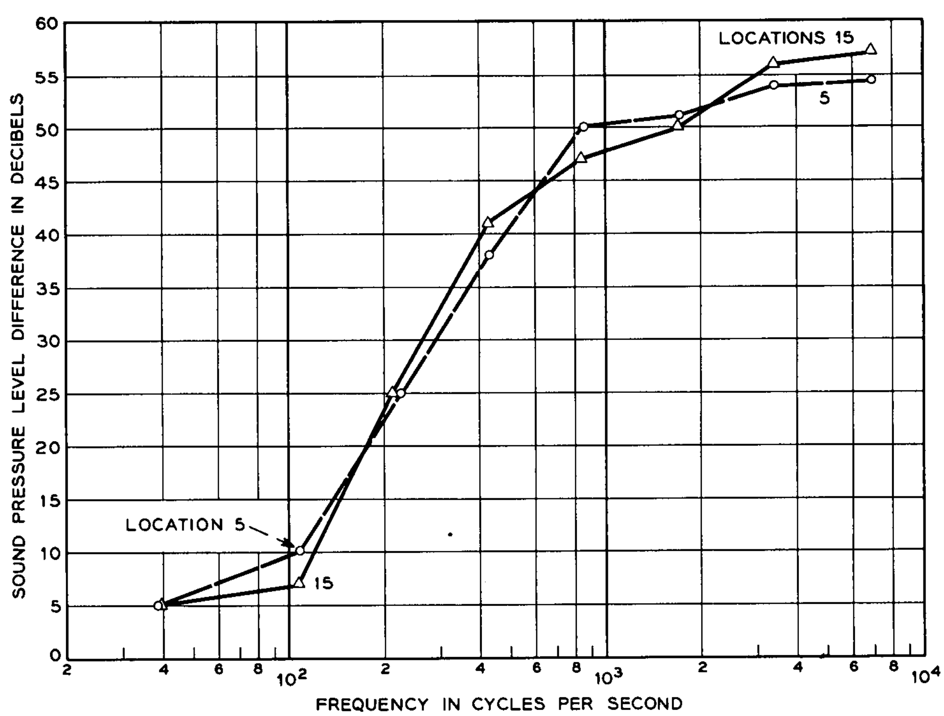

Figure 27. Sound Pressure Level Differences in Octave Bands for the Metal Booth — Locations 5 and 15

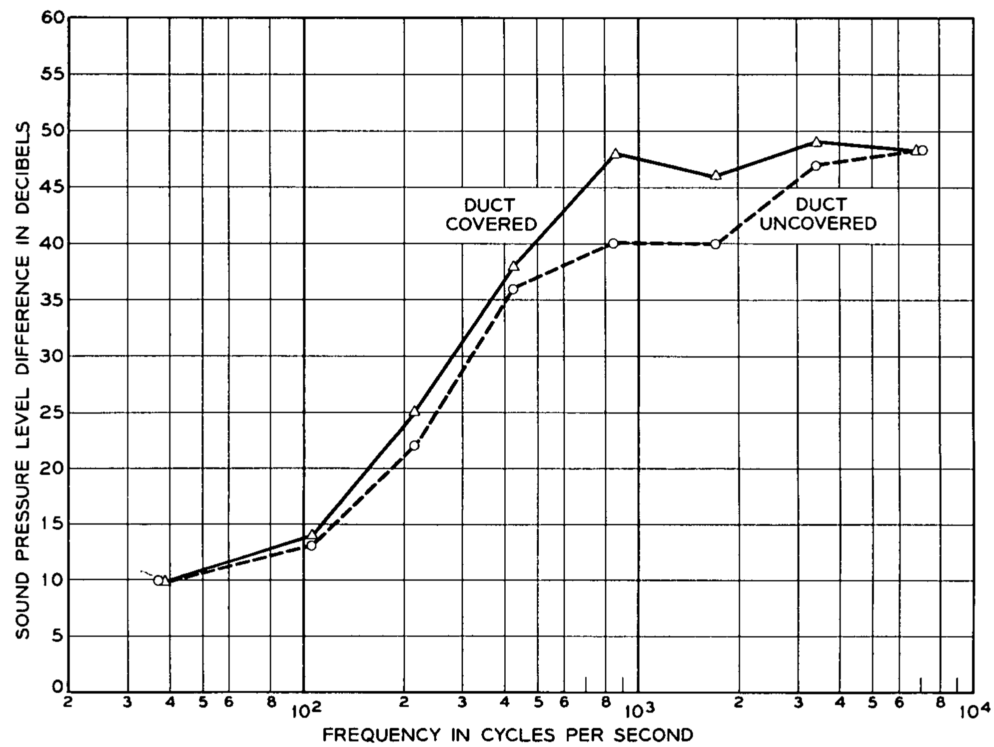

Figure 28. Sound Pressure Level Differences in Octave Bands for the Metal Booth — Location 16

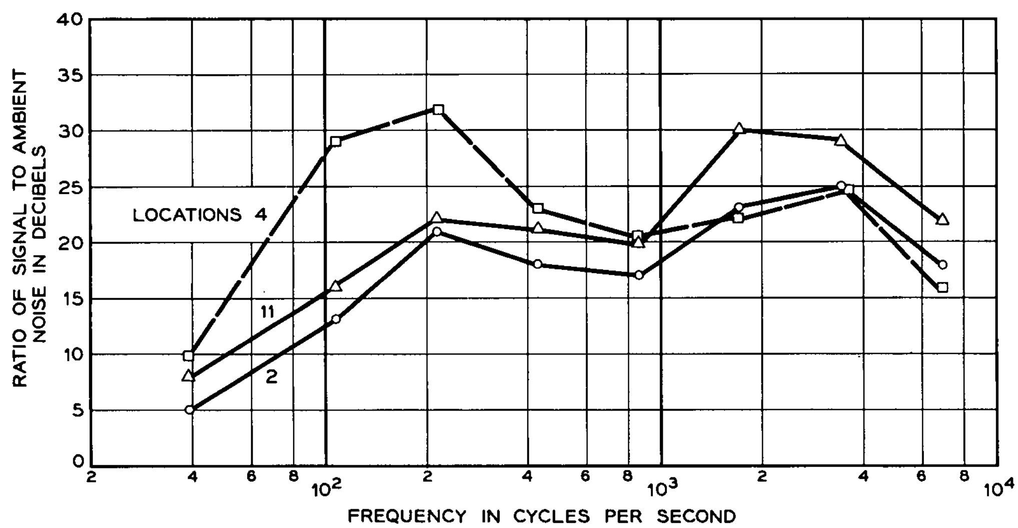

Figure 29. Signal-to-Noise Ratios for the Octave Band Noise Measurements

also shown for comparison. Sound pressure level differences for other locations are shown in Figures 22 through 28.

The level differences for locations 11 (Figure 24), 14 (Figure 26), and 16 (Figure 28) deserve an additional comment. The data for location 11 (at the door crack) show that the high frequency attenuation at this position is about 5 to 7 db less than at the wall locations. This slight high frequency leak can be confirmed by placing the ear near the door crack. The level differences for the upper and lower ventilating ducts, locations 14 and 16, show that the midfrequency range attenuation is reduced some 7 to 10 db when the duct cover is removed. This difference is also detectable by ear, and probably is derived from a partial acoustic "short circuit" between the input and output of the mufflers in the ventilating ducts. Level differences measured at all the other locations do not differ a great deal from one another. In particular, for the metal booth, the attenuation through the floor, location 15 (a weak point in the plexiglass booth), remains comparable to the wall attenuation.

The ambient noise level varied somewhat at different points in the laboratory rooms, but the S/N ratios for the octave band measurements were maintained reasonably high. Typical S/N ratios in octave bands are plotted in Figure 29.

b. Sine Wave Results

The sound level differences measured for high frequency sine waves are plotted in Figure 30. For these measurements, the sound level inside the booth was identical to that previously shown as the top curve in Figure 12. The attenuation for the metal booth could not be measured quite as high in frequency as could the plexiglass, owing to the greater attenuation of the former. However, as in Figure 13, the dotted curve in Figure 30 indicates a lower bound to the level differences. These results continue to indicate that the metal booth affords roughly 20 db more attenuation than the plexiglass. Continuous variation of the source frequency uncovered no significant "holes" in the response. Again, a measurement along the door crack, location 11, shows that the door gaskets afford somewhat less attenuation (in the order of 10 db at these frequencies) than do the wall structures. The dashed curve in Figure 30 shows that the lower frequency, octave band measurements mate reasonably well with the high frequency data.

c. Contact Microphone Results

The output of the contact microphone preamplifier, measured in octave bands, when the booth is excited inside by the noise field is shown by the second from the top curve in Figure 31. The top curve, plotted to a different ordinate, is the inside noise field. For these levels the S/N ratio of the contact pickup is exceedingly good. In fact, the signal available on the laboratory room wall opposite location 1 is

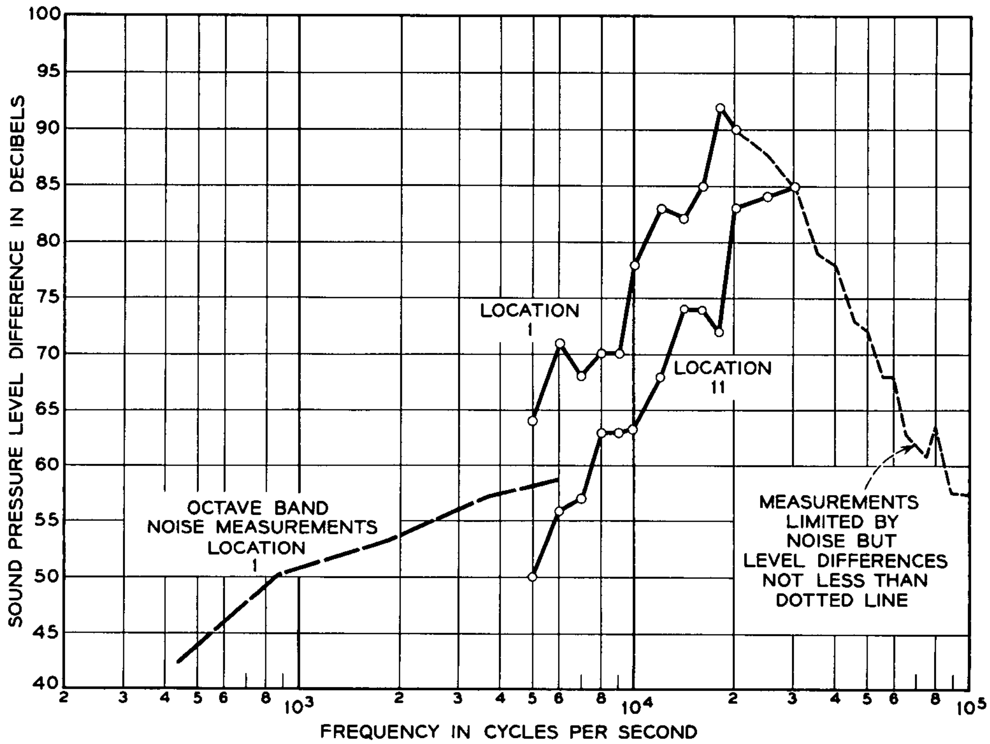

Figure 30. High Frequency Sine Wave Level Differences for the Metal Booth

entirely usable, and is shown by the curve second from the bottom. Subsequent considerations showed this signal to be produced mainly by airborne, rather than structure-borne sound. The ambient noise for the contact pickup is shown by the lower curve.

If the booth is excited by a flat spectrum noise, first from the inside and then from the outside, the differences in the octave band levels of the external contact microphone pickup are as shown in Figure 32. (Compare with Figure 15 for the plexiglass booth.) The results of two different measurements are shown. The multiple walls of the booth are quite effective in preventing the higher frequencies of the inside source from vibrating the outer wall of the booth. The level differences in the frequency region below about 500 cps, however, show that the contact output is only about 8 db less for the inside source than for the outside source. These data will be useful in deducing an optimum external noise spectrum for masking the contact pickup of speech inside the booth.

If the absolute calibration of the contact transducer is applied to its output, the absolute displacement of the outer wall of the booth can be computed for the noise excitations inside and outside. When this is done, the spectrum levels of

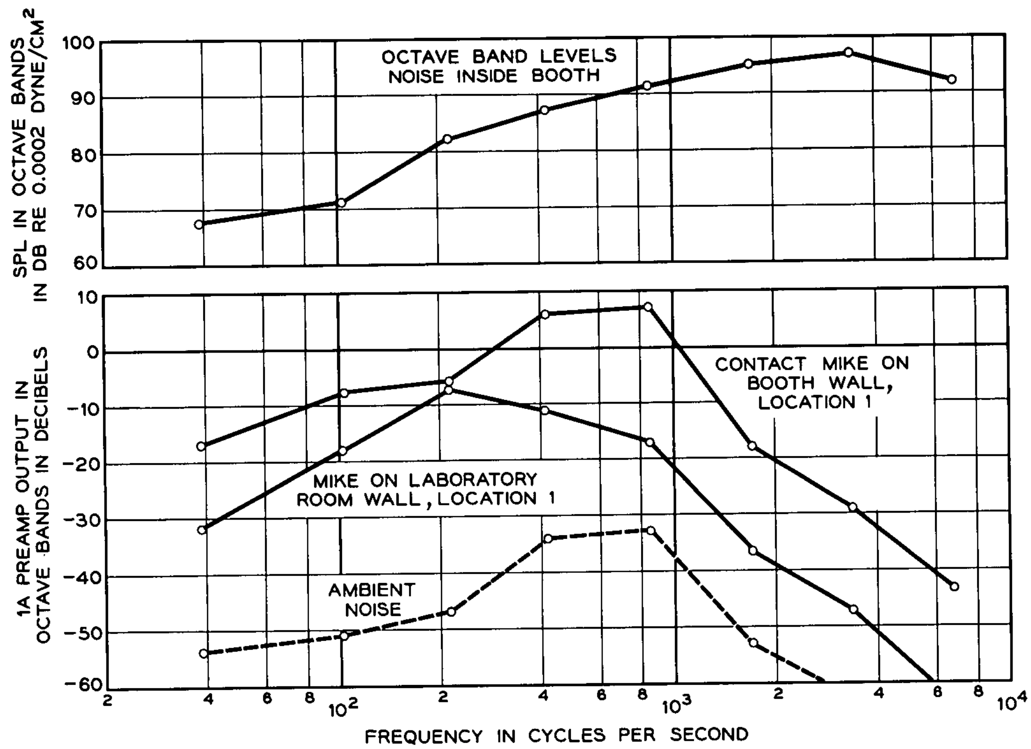

Figure 31. Octave Band Measurements for Contact Pickup on Outer Wall of Metal Booth

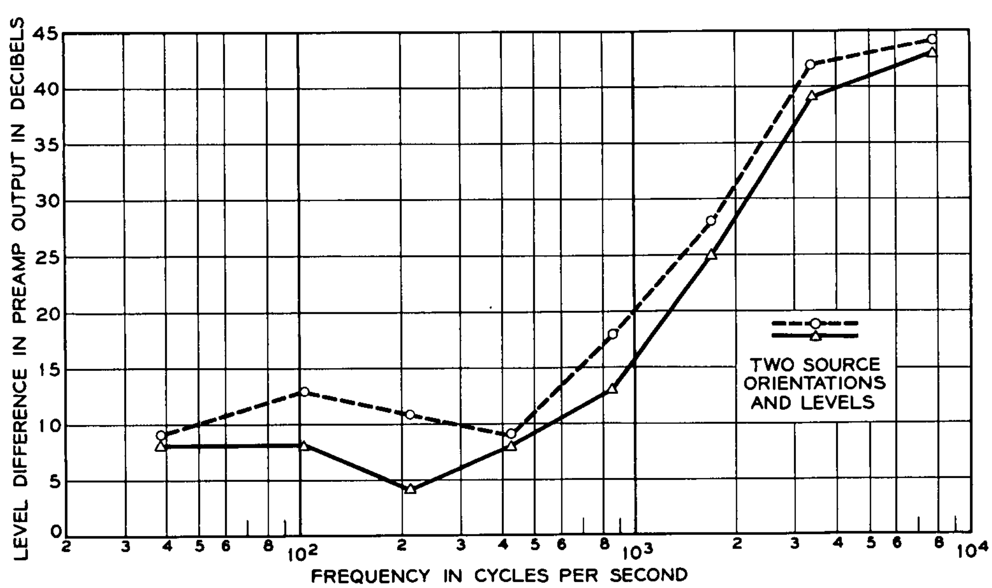

Figure 32. Difference Between the Octave Band Levels of the Contact Pickup for Excitation by the Same Source Inside and Outside

wall displacement, calculated from octave band readings, are those shown in Figure 33. In this case, the noise source has been corrected to have a perfectly flat power density spectrum, of spectrum level 55 db re 0.0002 dyne/cm^2, over the frequencies shown. These data can be roughly compared with those of Figure 14 for the plexiglass room. The latter are the approximate displacement responses to the same 55-db flat noise excitation. It can be seen that for the frequency range 600 to 1200 cps, the inside excitation produces a wall displacement of roughly -16 db re 5×10^{-7} cm in the plexiglass room, and about -31 db re 5×10^{-7} cm in the metal room. In the frequency range around 3000 cps, the same figures are about -56 db for the plexiglass room and about -80 db for the metal booth.

d. Speech Intelligibility Tests

In the word intelligibility tests for listening in the air outside the metal booth, two practiced male speakers recorded two lists of 50 PB words each in the carrier sentence previously described. This speech was played back at an over-all level of 78 db inside the booth. Two men sitting near the outside wall wrote down the test words they heard. The ambient external noise field measured approximately 45 db over all and was slightly greater than the ambient levels shown previously in Figure 22. (The ambient level for the listening tests is plotted in Figure 34.) The number of test words heard correctly out of each list of 50 for these two conditions is shown in Table VIII. The word articulation scores for the air listening are seen to range from 22 to 36 per cent.[8]

Table VIII

ARTICULATION SCORES FOR AIR LISTENING
WITH AMBIENT MASKING (METAL BOOTH)

Results of Articulation Tests on Metal Booth
Number of PB Words Correct Out of 50
Source Speech Level ≅ 78 db

Listener	Speaker NG	Speaker GH
BW	14	11
JF	18	11

[8] In comparing the measured word intelligibility scores for the two booths, it should be remembered that the tests were conducted in different environments. The plexiglass room was tested at the State Department where the parent room was large and relatively absorptive, the ambient noise level high (64 db), and the measured level differences great. The metal room was tested at Bell Laboratories where the parent room was small and hard, the noise level low (45 db), and the measured level differences minimal. These two conditions, for comparable levels of the speech source, operate to minimize the intelligibility scores for the plexiglass booth and to maximize the scores for the metal booth.

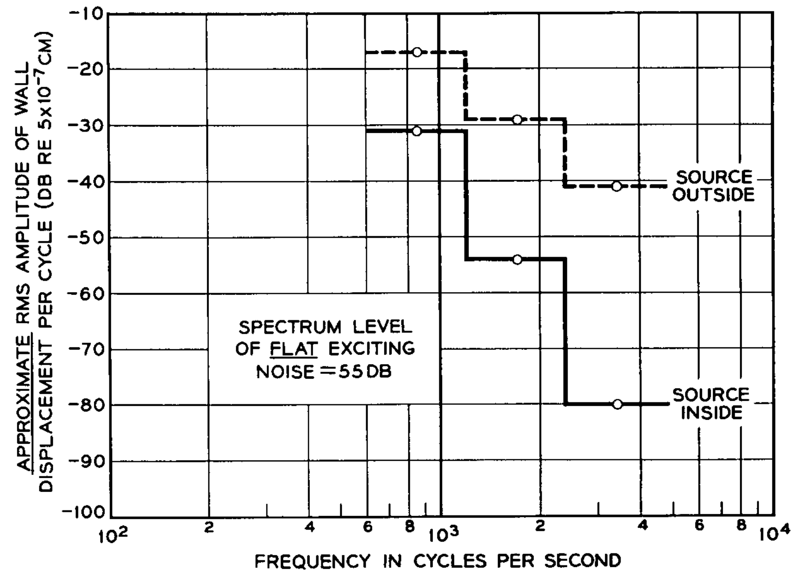

Figure 33. Spectrum Levels of Outer Wall Displacement for Flat Noise Excitation

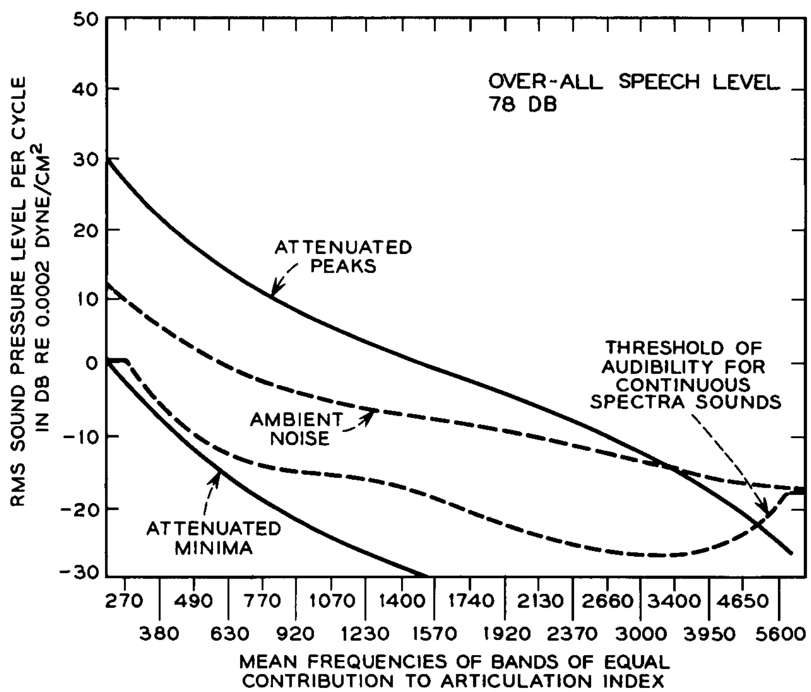

Figure 34. Computation of Articulation Index for Metal Booth Listening Tests

In connection with the air listening, a computation of the articulation index was made for the metal booth as previously done for the plexiglass booth. The computation was made for an average speech level of 78 db. If the spectrum levels for the speech peaks and minima are attenuated by the measured level difference for the metal booth (for example, those shown in Figure 22 for location 1), the speech peaks and minima outside the booth are essentially as shown by the solid curves in Figure 34. The spectrum level of the measured ambient room noise outside the booth is also plotted. The percentage of the "speech area" (between the attenuated peaks and minima) left uncovered by ambient noise and threshold, is the articulation index. For the metal booth this computation gives AI ≅ 0.2. In Figure 17, giving the relation between AI and word intelligibility, this computed word intelligibility is shown to be approximately 20 per cent for naive listeners and about 30 per cent for trained listeners. These figures agree relatively well with the measured scores.

In order to mask the speech area completely, as attenuated by the booth structure, a noise spectrum sloping at about -12 db/octave from 200 to 6000 cps and having a spectrum level of about 30 db at 200 cps would be sufficient. Integration of such a power density spectrum yields the over-all value of about 53 db re 0.0002 dyne/cm^2. By way of comparison, the comparable masking figure for the plexiglass booth was 68 db over all. As was the case with the plexiglass booth, the noise required for masking a contact pickup exceeds that for air listening.

More extensive intelligibility tests were performed for the contact microphone pickup because the speech thus received is a great deal more intelligible and is consequently more difficult to mask. Each of three different speakers read a 50-word list. Two men listened, first by means of a single channel contact pickup and then with a dual-channel pickup. The noise condition for all these tests was the ambient contact noise previously plotted in Figure 31. The results of the tests are shown in Table IX. The figures show that the contact pickup, under these favorable

Table IX

ARTICULATION SCORES FOR CONTACT PICKUP WITH AMBIENT MASKING (METAL BOOTH)

Results of Articulation Tests on Metal Booth
Number of PB Words Correct Out of 50
Source Speech Level ≅ 78 db

Listener	Speaker					
	JF		NG		GH	
	Single	Dual	Single	Dual	Single	Dual
JF	31	25	19	26	28	25
BW	27	23	15	26	22	29

conditions of background noise, give word articulation scores of the order of 40 to 60 per cent. This obviously represents a relatively high level of intelligibility and one for which appreciable masking is required.

From the measurements made in the previous section, it is possible to get an idea of the most efficient noise for masking the contact microphone pickup. The data in Figure 32 show that at low frequencies a source inside the booth produces about 8 db less wall displacement than the same source outside. At higher frequencies, the outside source produces displacements which exceed those of the inside source at a rate of about 12 db/octave. By way of example, assume the inside source to be speech at the previously discussed, conversational level of 69 db over all (see Figure 16). A crude, asymptotic approximation of the peak and minimum spectrum levels is that shown in Figure 35(a). According to Figure 32, an effective

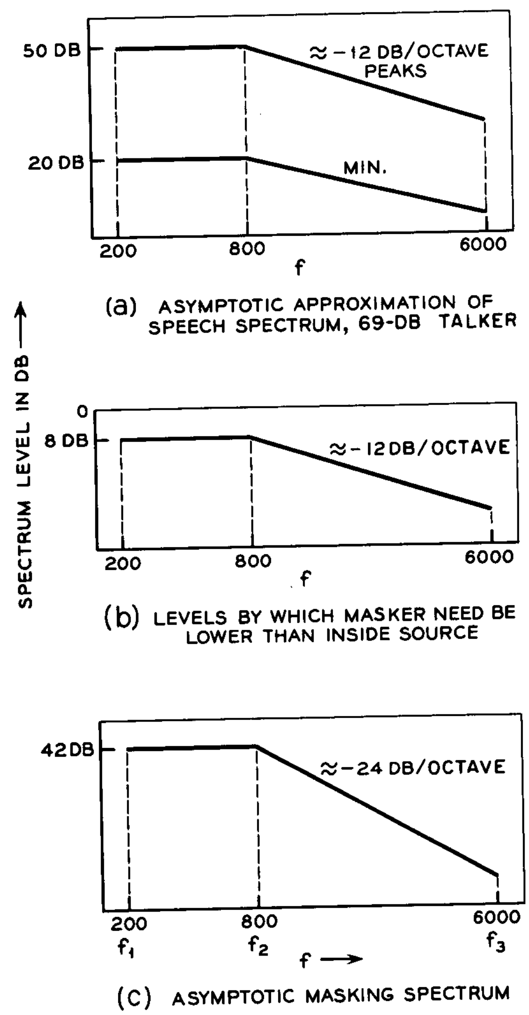

Figure 35. Asymptotic Noise Spectra for Masking Contact Pickup on Metal Booth

external masker need only have levels that are (asymptotically) lower than the speech peaks by the amounts shown in Figure 35(b). The asymptotic approximation to the most efficient external masking spectrum is therefore the curve for speech peaks in (a) of Figure 35, diminished by the curve (b), which results in curve (c).

The total over-all masking power provided by the noise source of curve (c) can be computed in a straightforward manner by integrating the power density between the limits 200 and 6000. The power density is described by:

$$P(f) = P_1 \; ; \; f_1 \leq f \leq f_2$$

$$= P_1\left(\frac{f_2}{f}\right)^4 , \; f_2 \leq f \leq f_3$$

the over-all (total) power is:

$$P_T = \int_{f_1}^{f_3} P(f)\, df$$

or,

$$P_T = P_1(f_2 - f_1) + \frac{P_1 f_2^4}{3}\left(\frac{1}{f_2^3} - \frac{1}{f_3^3}\right) .$$

In terms of decibels relative to the reference power corresponding to 0.0002 dyne/cm^2 sound pressure in a plane wave, the total power level, L, is:

$$L = 10 \log_{10} \frac{P_T}{P_0} = 10 \log \frac{P_1}{P_0} + 10 \log_{10}\left[(f_2 - f_1) + \frac{f_2^4}{3}\left(\frac{1}{f_2^3} - \frac{1}{f_3^3}\right)\right]$$

$$L = SL_1 + 10 \log_{10}\left[(f_2 - f_1) + \frac{f_2^4}{3}\left(\frac{1}{f_2^3} - \frac{1}{f_3^3}\right)\right] .$$

When the numbers for curve (c) are plugged into this relation the result is L = 71 db. The comparable figure for the plexiglass booth was 76 db.

If the speech source is louder than the 69-db over-all level, as it was in all of the listening tests, the masking noise spectrum must be increased appropriately. The 78-db speech level would therefore require an over-all noise level of about 80 db. As a rough check on this, the "speech-shaped" noise spectrum used previously with the plexiglass booth was also used to mask the contact pickup on the metal booth. The measured octave band levels outside and inside the booth, for an over-all level of 80 db, are shown in Figure 36. For this masking, it was not

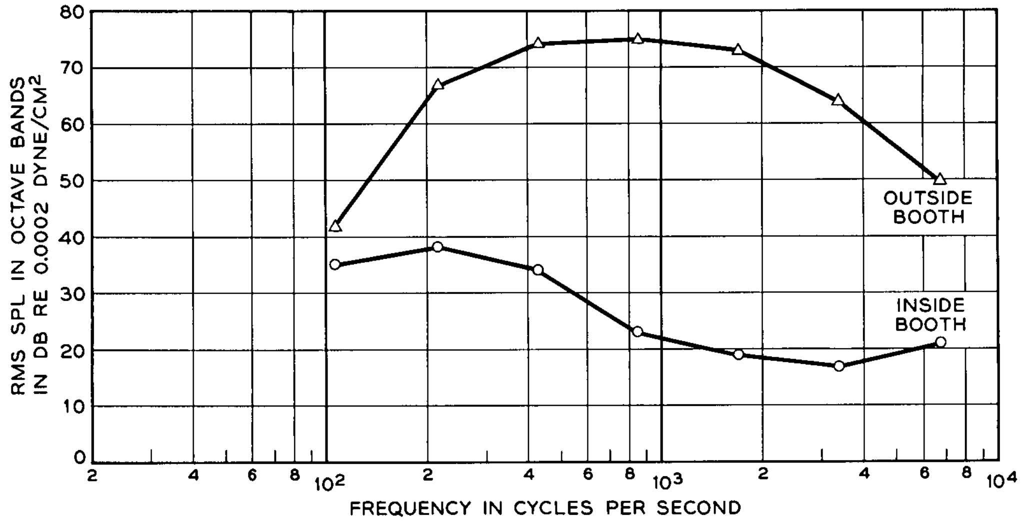

Figure 36. Measured Masking Spectrum for Contact Pickup on Metal Booth

possible to detect the speech signal in the noise, even when a long headphone line was run into an adjoining room so the listener was not in the noise field.

In addition to the acoustical masking of the contact pickup, some qualitative tests were performed to assess the masking provided by a mechanical vibrator in contact with the outer wall. As a convenience, the Bell Model 5A Artificial Larynx, held in direct contact with the wall, was used as the masker. This device produces periodic pulses of diaphragm displacement (similar to the pulses of air passing the vibrating vocal cords) at a frequency of about 120 cps. It could, however, be adapted for random excitation (shot noise). When applied anywhere on the same wall as the contact pickup, it amply masked 78-db over-all speech inside the booth (in fact, the first time it was used the unsuspecting listener was acoustically traumatized!). The external sound it radiated into the parent room measured 54 db over all and exhibited a spectral shape which was an effective masker of the airborne sound. The noise the vibrator produced inside the booth was scarcely above the inside ambient level. When applied to a wall without the pickup, the larynx was less effective in masking (i.e., the surface vibration did not travel well around the corners of the booth). It would not be impractical, however, to use a vibrator on every external wall surface.[9]

[9] This device was not tried on the plexiglass room. It is understood that similar tests were made at the State Department and this idea was found to have some objectionable features when applied to the plexiglass room.

2. ELECTROMAGNETIC RESULTS

The results of the electromagnetic radiation measurements carried out according to the procedure of Section III, paragraph 4, are as follows:

Frequency (mc)	Worst Case Attenuation (db)
30	78
49	>73
205	>73
975	>77
10,000 at ventilator	46
10,000 except ventilator	60

As before, the minimum attenuations occurred in the vicinity of the ventilators and the power filter box. Comparing these results to those of Section IV, paragraph 2 shows that at the lower frequencies (below 1000 mc) the metal booth gives attenuations ranging from 5 to 20 db in excess of the screen room inside the plexiglass booth. At the 3-cm wavelengths, the attenuations for the two rooms are comparable.

3. MAGNETIC FIELD RESULTS

The magnetic field measurements on the metal booth showed attenuations of the order of 30 db at the midaudio-frequency range. This figures exceeds by some 25 db the comparable measurement for the plexiglass booth. The improvement stems from the eddy-current shielding of the two aluminum walls, and the relatively high permeability of the inner steel sound pans. Significant magnetic leaks were found around the doors of the metal booth where the acoustic and r-f gaskets have low permeability. At these points the magnetic attenuation fell to about 20 db. A plot of these data is shown in Figure 37.

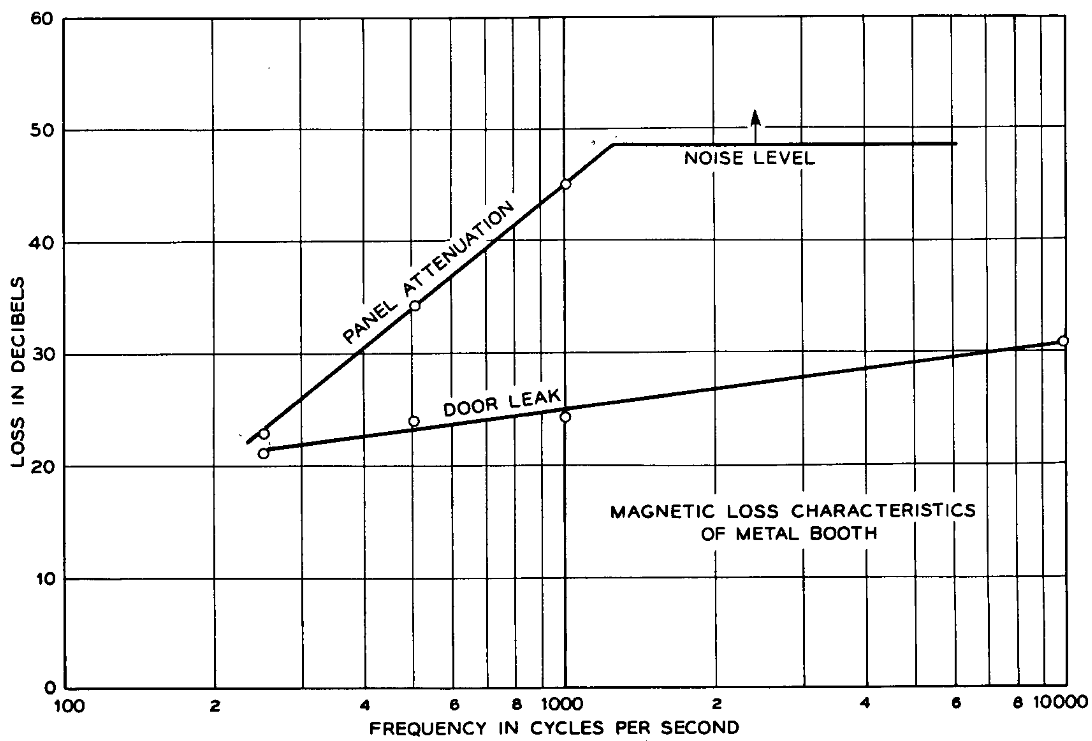

Figure 37. Magnetic Attenuation of Metal Booth

Section VI. DISCUSSION

1. RELATION BETWEEN TRANSMISSION LOSS (TL) AND LEVEL DIFFERENCE (ΔL)

Throughout this report, the acoustic attenuations of the two booths have been presented in terms of the level differences between the sound pressures measured inside the booths and those measured outside. As pointed out earlier, this level difference is uniquely related to, but generally not the same as, the transmission loss figure obtained conventionally in laboratory measurements on wall panels. If τ is defined as the ratio of acoustic energy transmitted through a wall to the acoustic energy incident upon it, then the transmission loss is defined as:

$$TL = -10 \log_{10} \tau .$$

Numerous studies have been made of the techniques for measuring the level difference and relating it to the transmission loss for a wall or panel. One of the more comprehensive is that by London.[10] Beranek[11] shows that London's results are relatively well described by:

$$TL = L_1 - L_2 + 10 \log_{10} \left(\frac{1}{4} + \frac{S_1}{R_2}\right)$$

$$= \Delta L + 10 \log_{10} \left(\frac{1}{4} + \frac{S_1}{R_2}\right)$$

where:

L_1 is the spatial mean of the reverberant field spl on the source side of the wall.

L_2 is the spl in the immediate vicinity of the wall on the receiving side.

ΔL is the level difference.

S_1 is the area of the transmitting wall.

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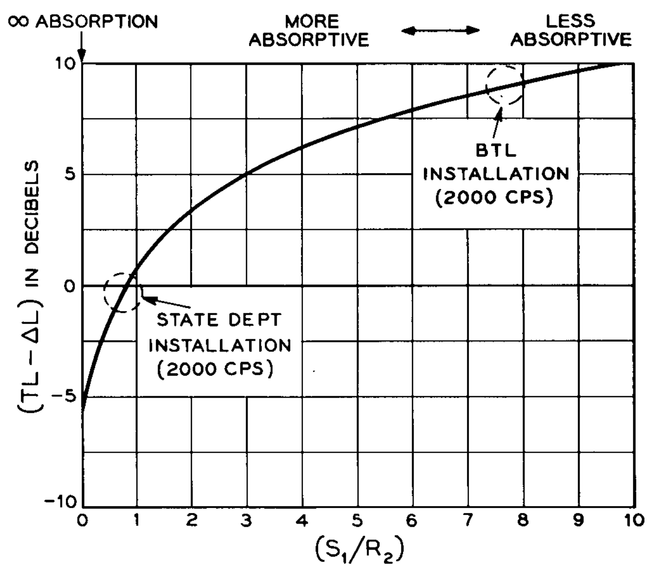
[10] A. London, "Methods for Determining Sound Transmission Loss in the Field," J Res Nat Bur of Stand 26 (May 1941), 419-453.

[11] L. L. Beranek, Acoustics, McGraw-Hill Book Company, Inc., New York, 1954.

R_2 is the room constant for the receiving room, and is equal to $[S_2\bar{\alpha}/(1-\bar{\alpha})]$, where S_2 is the total surface area of the receiving room and $\bar{\alpha}$ is the mean absorption coefficient for the receiving room. The absorption coefficient is, of course, dependent upon frequency.

If the booths with the noise sources inside are considered as a uniform wall, the above relation is useful for estimating the TL. As the equation shows, the difference between the TL and ΔL is a function of the outer surface area of the booth and the sound absorption present in the parent room. This difference is plotted in Figure 38.



$$(TL - \Delta L) = 10 \log_{10} (S_1/R_2 + 1/4)$$

Figure 38. Relation between Transmission Loss and Level Difference

The outer surface areas of the metal and plexiglass booths are roughly calculated to be 750 and 800 square feet, respectively. These figures may be taken as approximations to S_1. The dimensions of the containing, or parent, room used for the Bell Laboratories measurements are 23 by 23 by 12 feet. Two of the walls are faced with plaster board on furring strips, two are of hard plaster on masonry, the hung ceiling is plasterboard on a wooden frame, and the floor is linoleum on concrete. The room constant for this room at 2000 cps is estimated to be about 100 sabins. For the Bell Laboratories test room, at a frequency of 2000 cps, then, the ratio S_1/R_2 is put at approximately 7.5 for the metal booth and 8.0 for the plexiglass.

The parent room for the State Department installation of the plexiglass booth was substantially larger than the Bell Laboratories test room. Its dimensions are roughly 27 by 48 by 13 feet. The floor is vinyl tile, the walls hard plaster, and the ceiling is treated with blown mineral wool. Taking the absorption coefficient of the ceiling to be about 0.6 at 2000 cps, the room constant is estimated to be of the order of 900 sabins. For the State Department installation, this places the ratio S_1/R_2 at about 0.8 for the metal booth and about 0.9 for the plexiglass booth. The regions appropriate to the absorptive characteristics of the two parent rooms at 2000 cps are indicated in Figure 38.

At 2000 cps, therefore, one expects that the level differences measured at the State Department installation should be equal to or slightly greater than the TL, and that the Bell Laboratories level differences should be somewhat less than the TL. According to the curve in Figure 38, the difference between the level differences measured at the Bell Laboratories and State Department locations should be of the order of 10 db at 2000 cps. The measured level differences for the plexiglass booth in both locations is shown in Figure 39. At low frequencies they are approximately the same, but depart at high frequencies. At 2000 cps, the State Department level differences are roughly 10 db greater than those obtained at the Bell Laboratories location.

During the design of the metal booth, transmission loss measurements were made on the panel structure at the Riverbank Laboratories.[12] In Figure 40 these TL data are compared to typical level differences measured at the Bell Laboratories installation. Again it can be seen that at the frequency chosen for the previous discussion, namely 2000 cps, the transmission loss is about 10 db greater than the level difference.

These considerations point up the influence which the parent room can have upon the sound pressure level produced outside the booth by a source or talker inside. It is clear that if the parent room is small and hard (nonabsorptive) and has a low ambient noise level, conditions are more favorable for airborne sound pickup than if the parent room were large, absorptive, and in a region of high ambient noise. It is obvious that a greater external level of masking noise would be required to safeguard the former situation than would be required to safeguard the latter. The unfavorable properties of a small parent room can, of course, be alleviated to a certain extent by increasing its absorption coefficient with appropriate acoustical treatment.

[12] These data were kindly supplied by Mr. Hale Sabine.

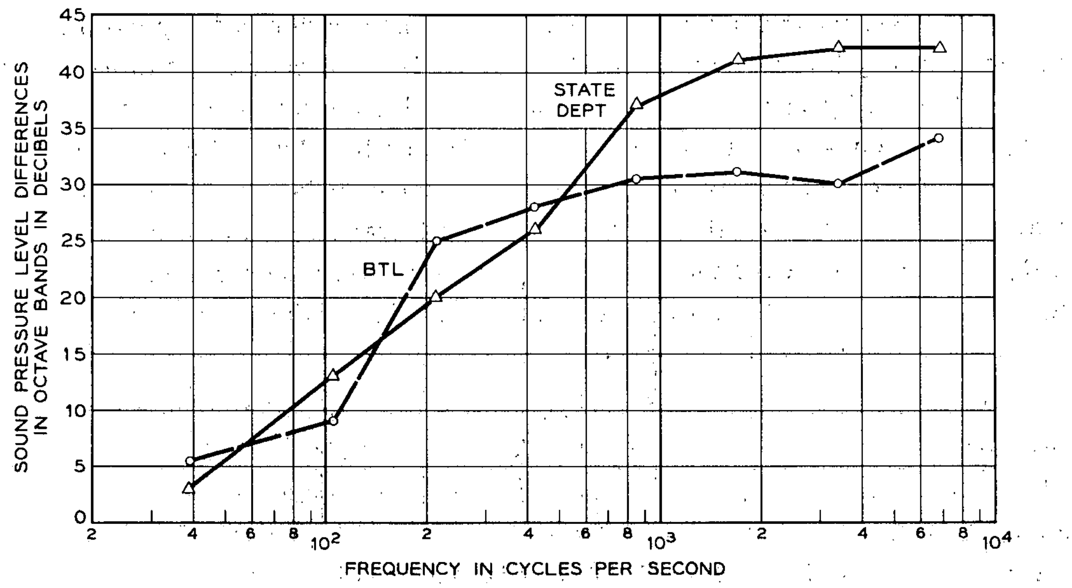


Figure 39. Comparison of Level Differences for the Plexiglass Booth Measured at the State Department and Bell Laboratories Installations

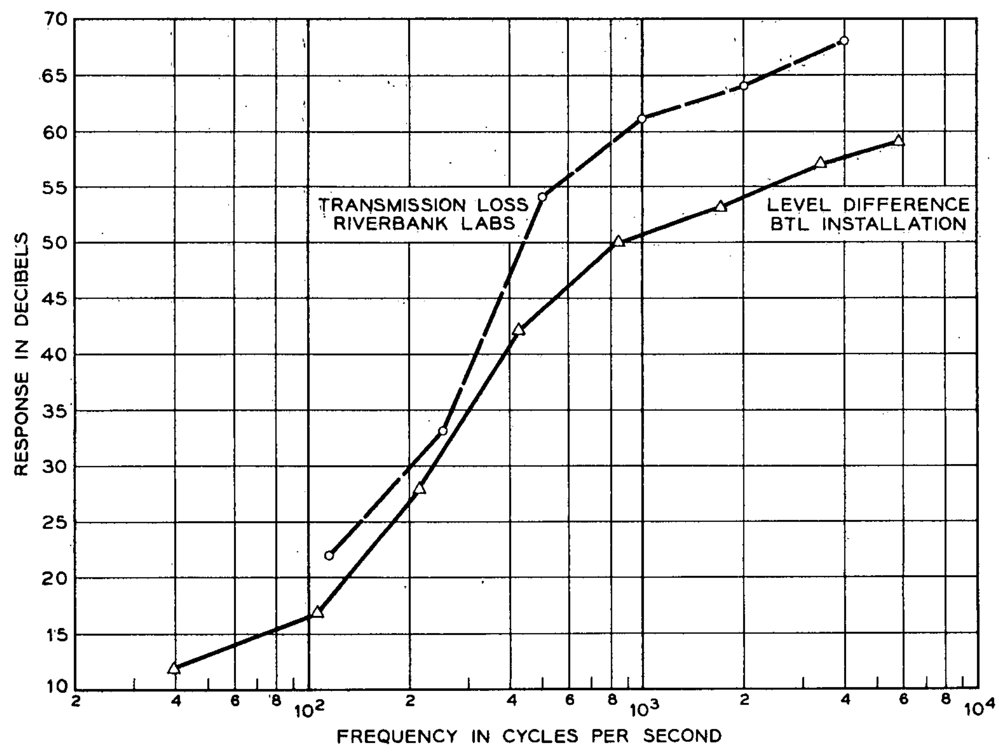


Figure 40. Comparison of Measured Transmission Loss and Level Differences for the Metal Booth

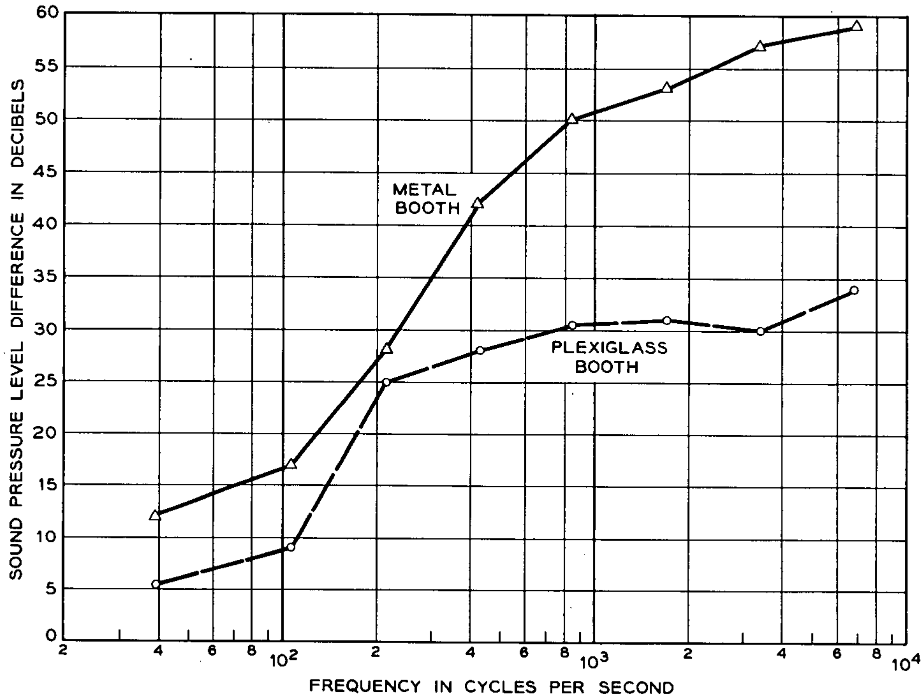


Figure 41. Measured Level Differences for the Metal and Plexiglass Booths for Octave Bands of Random Noise

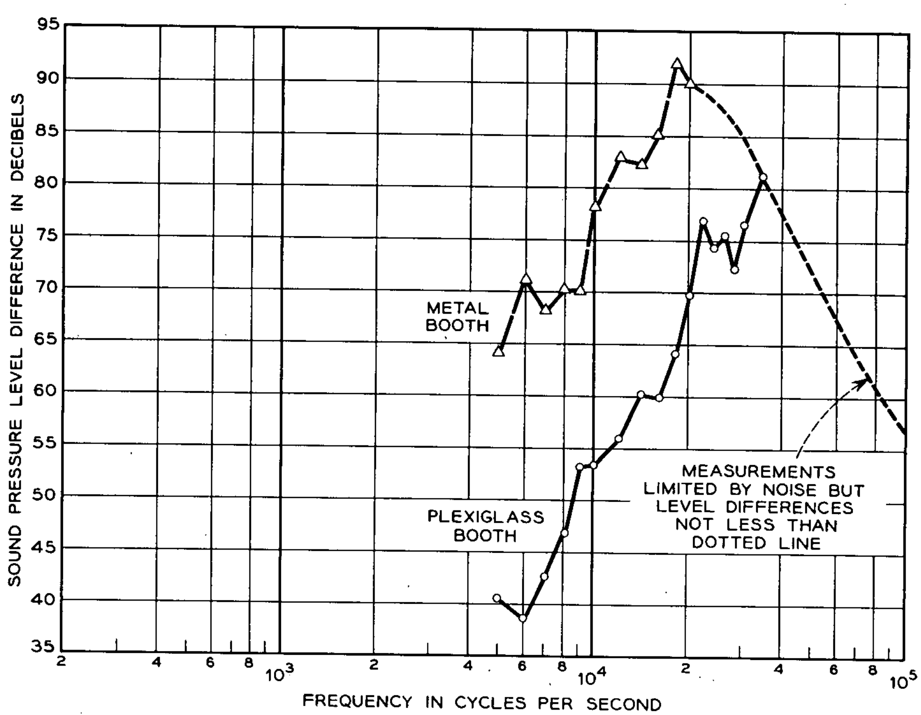


Figure 42. Measured Level Differences for the Metal and Plexiglass Booths for High Frequency Sine Waves

2. COMPARATIVE TECHNICAL PERFORMANCE OF THE BOOTHS

In all of the technical measurements performed in this study, the results clearly show that the performance of the metal booth is superior to that of the plexiglass booth. Over the midrange of speech frequencies the acoustic attenuation of the metal booth is about 20 db greater than that of the plexiglass room. This comparison is drawn in more detail in Figure 41 where audio level differences are shown for comparable environmental conditions. The metal booth's superiority is sustained into the ultrasonic region as the comparison in Figure 42 shows. For both booths the external speech signals available for air and contact pickup can be reliably and securely masked by specially shaped noise spectra whose over-all levels fall in the neighborhood of 80 to 85 db. (This assumes that loud speech, of the order of 78 db over all, <u>might</u> be produced inside the booths. The controlling criterion is the contact pickup.) The noise level resulting inside the metal booth from such an external masker would not be annoying. For the plexiglass booth, the resulting inside level borders on the objectionable, particularly for long periods of exposure.

It is worth considering briefly the possibilities for improving the acoustic attenuation of the plexiglass booth. Very little of a superficial nature would help substantially. Shock mounts, of course, are a must in reducing the structure-borne sound. (These were not provided in the Bell Laboratories installation.) This should also include shock mounting or isolating the steps up into the room. Some major redesign of the walls seems indicated if they are to be substantially improved. The double-wall idea should be retained, but the walls should be isolated from one another rather than in rigid contact. (The effects of rigid coupling is dramatically pointed up by the greater transmission through the floor of the booth.) A brute force increase in attenuation can always be had by increasing the wall mass per unit area, but this is objectionable from the standpoint of portability. A complete suspension of the inner room on vibration mounts would seem to be a more efficient approach.

If another 10 to 20 db of attenuation were gained by improving the basic plexiglass structure, the door, as it presently exists, would then probably become the weak point. If an audio band attenuation of the order of 40 db or better is to be achieved, a double door will in all probability have to be resorted to. Only through careful adjustment and maintenance can the latter be avoided. Like the door, the ventilating ducts, which now are as good as the rest of the room, may also become weaknesses, and would have to be re-examined for isolation and attentuation.

The electromagnetic shielding of the metal booth is slightly better than the screen room of the plexiglass booth at frequencies below 1000 mc. With a little additional care in the screen room, indications are that the radio frequency attenuation of both rooms can be made comparable. The arrangement for fitting the screen room inside the plexiglass room, however, seems very undesirable from both security and acceptability standpoints.

There is virtually no magnetic attenuation provided by the plexiglass room, while that of the metal booth is only marginally secure. Magnetic masking (which normally does not annoy humans) is easier to implement than adequate magnetic shielding at the lower audio frequencies.

Security is a relative thing, and criteria of security must be tailored to suit particular situations. The criteria must involve subjective as well as objective considerations simply because people are involved in the security situation. To make categorical decisions as to "secure" or "unsecure" solely on the basis of technical measurements may be equally as dangerous as making the decisions solely on the basis of psychological factors. There is obviously little point in having a technically secure structure if it is so unsightly, uncomfortable, and unpleasant that no one will use it. There is equally little point in having a comfortable, pleasant booth which can be violated with minimal effort.

The obvious implication is that any security criteria demand a weighting of subjective and objective factors. This study has been concerned almost exclusively with ascertaining the physical performance of the structures. It is difficult to carry this out without also offering some interpretation of the results. Such interpretation has led logically to the recommendations given at the beginning of this report. These recommendations have not been blind to psychological factors. Our recommendations have, however, stressed technical security because we feel that it is the primary requisite. Acceptability, livability, and aesthetics should be subordinated to it, and should be recognized by potential users as subordinate. In the long run this would seem a small price to pay for the additional security.

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